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Assessment of groundwater recharge from the dam of Wadi Al-Jizzi, Sultanate of Oman

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College of Graduate Studies

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A Thesis submitted to

College of Graduate Studies
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By

Rashid Said Al-Kindi

In partial fulfillment of the requirements for the
M.Sc Degree in Water Resources

College of Graduate Studies
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Thesis Title

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Abstract

Water is the most precious resource in arid and semi-arid countries including the Sultanate of Oman. In such countries, groundwater is regarded a major source of water. However the long-term yield of aquifers should be evaluated. Annual recharge of groundwater resources, in such areas, is generally small but groundwater levels may also recover dramatically during wet years.

Due to the increase in population and the associated increase in agricultural and industrial activities groundwater abstraction from the different aquifers in Oman has increased tremendously since the mid 1970. This over exploitation of the groundwater resources has led to a considerable decline in the subsurface water levels and hence affected the water balance in the interrelated hydrogeological systems.

Although surface water is not always a major source of water it is sometimes feasible to build dams across the main Wadis to provide water for domestic and/or irrigation purposes. The collected surface water at dams can also be used to recharge the depleted aquifers. This is quite true in arid and semi-arid regions. The Sultanate of Oman is no exception.

Efficient management of groundwater resources is not only needed but also necessary to provide a sustainable groundwater supply. Artificial recharge of aquifers, application of water conservation plans, water and wastewater reuse, and improved irrigation methods are some of the techniques which could be used to increase the availability and sustainability of water resources. To that end, eighteen dams have been built in the Sultanate of Oman since the mid 1986. These dams are mainly built to recharge the groundwater systems and minimize the seawater intrusion in the coastal areas.

The basic idea of any recharge dam is to hold the surface water runoff that might develop from heavy rainfall events in a particular wadi at a location where the recharge to the groundwater is desired. The water is either infiltrated from the reservoir in the upstream side of the dam to the underlying aquifer or released through culverts to infiltrate downstream through the wadi channel. The efficiency and performance of the constructed dams as an effective tool for groundwater recharge need to be investigated and assessed.

The main objective of this research is to study the efficiency of the recharge dam and simulate the groundwater conditions at Wadi Al-Jizzi. The same methodology can thus be considered in the assessment of the performance of other dams of similar hydrogeological and physical setting. To that end, all previous studies and reports related to wadi Al-Jizzi have been reviewed. Physical, geological, hydrological and hydrogeological settings of the area have been identified. All available records for groundwater levels and quality have been assessed and presented in different forms for analysis. The trends of groundwater levels during the last two decades have also been identified.

The USGS finite difference groundwater model "MODFLOW" has been employed to simulate the groundwater conditions in Wadi Al-Jizzi. The study domain (30km x 30km) was discritized into a total number of 22500 regular cells. Each cell has dimensions of 200m x 200m. Various types of boundary conditions were applied to accurately simulate the field conditions. Several assumptions were made. The aquifer was assumed homogeneous, the hydrodynamic dispersion effects were neglected, the flow in the aquifer was assumed fully horizontal, the flow in the aquitard was assumed vertical and the saline groundwater was assumed at rest.

The model parameters were calibrated for the period 1985 to 1994 until a good match between the observed and simulated groundwater levels was obtained. The model was then validated, without changing the calibrated parameters, for the period 1995 to 2002. Predictions were made for the groundwater levels till the year 2020 assuming no change in groundwater abstractions and same climatic conditions.

Pumping of groundwater resources in Wadi Al-Jizzi area should be reduced and controlled as much as possible. A database regarding the geological and hydrogeological setting should be established.

Further development of the present numerical model might be essential to better simulate the groundwater levels and study various scenarios for groundwater pumping and management. This would help achieve the conservation of groundwater resources in Wadi Al-Jizzi catchment. The proposed scenarios should take into account the political, economical and social impacts. The Water Resources National Master Plan for integrated management of all available water resources should be updated and implemented. This master plan should account for dry and wet conditions.

Keywords: Sultanate of Oman, Wadi Al-Jizzi, groundwater, recharge, dams, numerical simulation, MODFLOW

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Chapter 1. Preliminaries and Problem Identification

1.1. Introduction

The Sultanate of Oman occupies the south-east corner of the Arabian Peninsula and lies in an arid region, Figure 1.1. The coastline extends for about 1,700 km from the Strait of Hormuz in the north to the borders of the Republic of Yemen in the south occupying a total land area of approximately 309,500 km².

The Sultanate of Oman is the third largest country in the Arabian Peninsula after Saudi Arabia and Yemen. It overlooks three seas: the Arabian Gulf, the Gulf of Oman and the Arabian Sea. Oman borders Saudi Arabia and the United Arab Emirates in the West, the Republic of Yemen in the South, the Strait of Hormuz in the North and the Arabian Sea in the East. The country consists of eight administrative regions: Muscat, Dhofar, Musandam, A'Dhahira, Al Batinah, A'Dakhliyah, Al Wusta, and Al Sharqiya, Figure 1.2. The total population of Oman is about 2.4 million (MNE, 2000), 28% of this population is in Al-Batinah region itself.

The topography of Oman consists of plains, desert, mountain ranges and wadis. Mountain ranges occupy 15% of the total area and extend for about 700 kilometers from the north to the south with a width varying between 30 and 130 kilometers (Al-Ghilani, 1996). The two main mountain ranges are the Hajar range, running from Musandam to Ras al Hadd, and the Qara range in Dhofar, which attracts the light monsoon rains during the mid-summer months. Around 82% of Oman area is desert.

There are considerable variations of climatic conditions within the country due to its size and configuration of its topography. Summer starts in May and ends by October while winter extends from November to April. The climate differs from the coastal areas to the interior ones, but is generally described as hot and humid.

Figure 1.1. Location map of the Sultanate of Oman

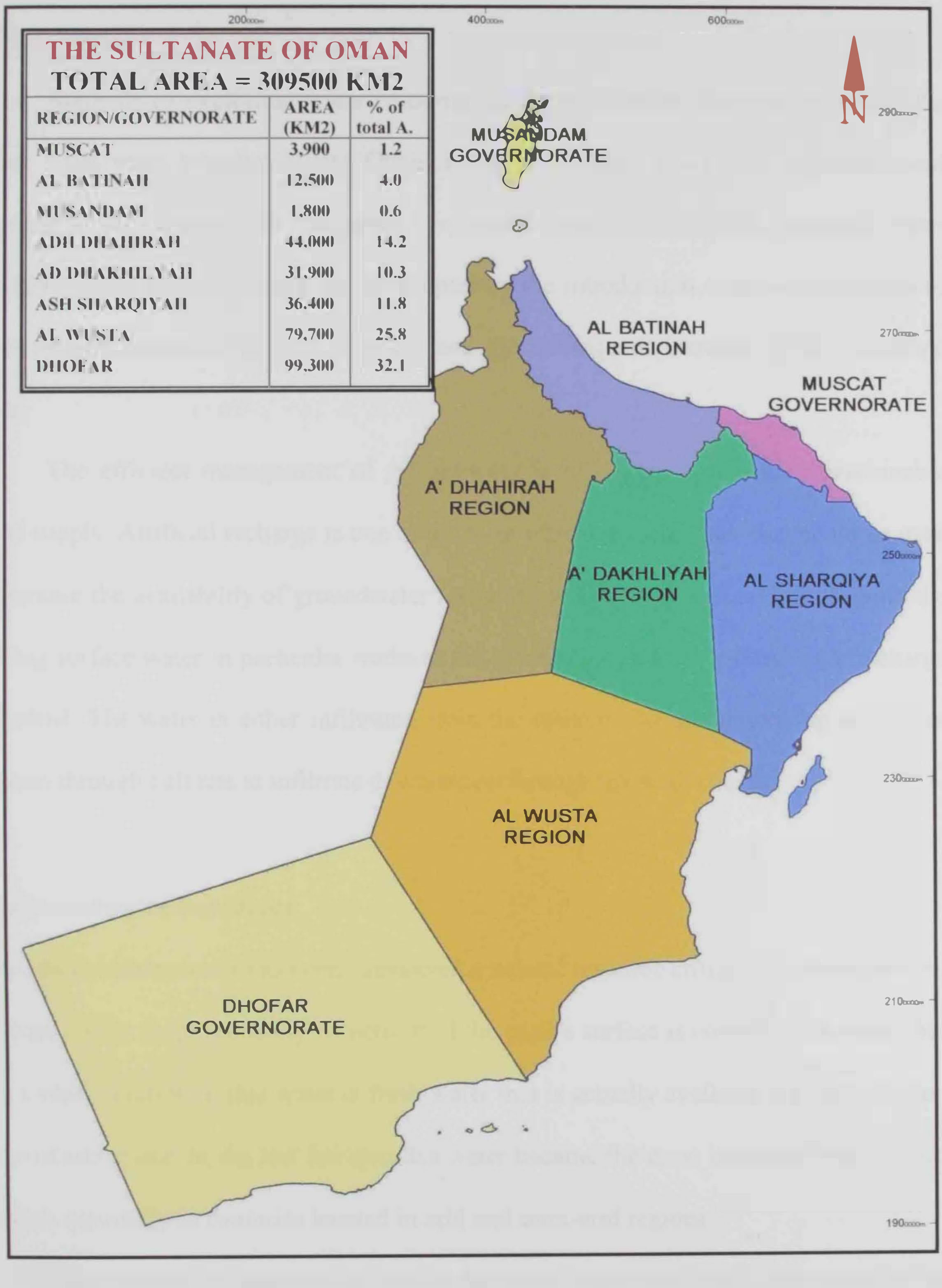

Figure 1.2. Regional and Governorate map of the Sultanate of Oman

Rainfall is generally light and irregular. The average annual rainfall varies from less than 50 mm in central Oman to more than 300 mm in the Northen Oman Mountains (MWR, 1995).

Methods of exploiting water resources in the past varied from one region to the other. Aflaj were introduced into Oman about a thousand years ago and were used throughout the Interior for irrigation. In recent years the balance between water availability and water demands has been upset by the introduction of modern methods of extracting subterranean sources of water and the subsequent increase in the cultivated areas.

The efficient management of groundwater is necessary to provide a sustainable water supply. Artificial recharge is one of the most effective techniques that could be used to increase the availability of groundwater resources in Oman. Dams are built to hold the flowing surface water in particular wadis at the locations where the groundwater recharge is desired. The water is either infiltrated from the reservoir to the underlying aquifer or released through culverts to infiltrate downstream through the wadi channel.

1.2. Groundwater Resources

Throughout history water has been considered a natural resource critical to human survival (Biswas, 1997). Approximately 70 percent of the earth's surface is covered with water, but only a small fraction of this water is fresh water that is actually available for consumption and productive use. In the last few decades water became the most important resource on the earth especially in countries located in arid and semi-arid regions.

Groundwater is regarded as one of the most important water resources in the world. Amongst the various source options, groundwater is by far the most potable and safe water in nature (WHO, 1984). In arid regions it might be the only source of freshwater, supplying a large proportion of water globally. It is therefore, essential to know how long the groundwater resource will last and to determine the present recharge rates. Some aquifers, especially in arid and semi-arid regions, contain paleowaters (fossil groundwater) stored from earlier periods of wetter climate.

There are natural changes in groundwater levels because of climate change (drought, pluvial episodes), but the main changes are due to human abstraction. Groundwater, which makes up about 14% of the earth's fresh water and amounts to approximately 4 million km^3, moves through the openings that exist within the natural materials forming the earth's surface (Roberson *et al.*, 1995).

Groundwater is stored in the spaces and cracks between particles of soil, sand, gravel, rock or other materials. Groundwater moves only if sufficient pressure, or head, is available to force water through the spaces between porous aquifer materials. The rate of movement is determined by the hydraulic gradient, permeability and porosity of the material.

Groundwater is recharged by natural or artificial processes. Most of the arid countries including Oman depend on groundwater as a main supply of freshwater. Groundwater is much cheaper than desalinated water. It does not require complex and huge equipment or structures as in the case of desalination plants.

1.2.1. Classification of aquifers

Groundwater is stored in the voids, spaces and cracks between particles of soil, sand, gravel, rock or other materials. These cracks or space can include fractures, faults, bedding planes, solution channels (limestone formations), dissolution channels associated with more easily weathered material or other structural features such as bed planes or deformation in the bedrock due to folding. These materials form what is called the groundwater aquifer or reservoir.

Groundwater is not usually static but flows through the rock and soil voids. Water movement toward groundwater may take hours or years, depending on the depth to the aquifer and the characteristics of the unsaturated zone. Under natural conditions, a balance could exist between the volume of water entering an aquifer and the volume of water being discharged from an aquifer. The decline of the hydraulic head with time is mainly due to over-pumping of the aquifer. There are two main types of aquifers, confined aquifers and unconfined aquifers. Confined aquifers, or artesian aquifers, are saturated formations between low permeability materials that restrict the movement of water into or out of the saturated zone. When confined aquifers are pumped piezometric heads often decline rapidly over large areas and generally will recover to normal when pumping ceases. Unconfined aquifers are often called water table aquifers because they have no layers that restrict water movement into the saturated zone from above. The upper water surface of an unconfined aquifer is called the water table and is subject to an atmospheric pressure (Driscoll, 1989).

The storage in unconfined and confined aquifers is different due to the formation of the aquifer. In unconfined aquifers the water is pumped from drained void space, while in confined aquifers the water is pumped from decompression of both the water and the sediments of aquifer materials.

Aquifer parameters of storativity, transmissivity and thickness represent the mechanisms controlling the dispersal of infiltrated water. Aquifers with high values of specific yield and hydraulic conductivity can store significant amounts of water, as well as diposal of water in different directions. Aquifer parameters influence the growth of the groundwater mound underneath the recharge channel (Abdulrazzak *et al.* 1991).

The same change in water table represents a larger amount of water if taken from an unconfined aquifer as compared to a confined aquifer. In unconfined aquifers, for a 1-m decline in the water table, the volume of water produced per unit aquifer area is the specific yield. In confined aquifer, for a 1-m decline in the potentiometric (piezometric) surface, the volume of water produced per unit aquifer area is the storativity, S.

Several important aquifer systems are encountered in the sultanate of Oman. The main systems include alluvial aquifers, regional Quaternary aquifers of the Hajar Super Group in Northern Oman, aquifers of the Hadramawt Group and aquifers of the Fars group (MWR, 1999b).

1.2.2. Groundwater flow systems

Groundwater moves from high water elevations (high pressure or head) to low subsurface water elevations (low pressure or head). In general, the water flows more rapidly where large differences exist in water surface elevations (steep hydraulic gradients), but this is not always the case. A large variation in the hydraulic gradient could also mean a lower formation permeability. Groundwater may move toward, or away from, streams or lakes depending on the hydraulic gradient. As groundwater moves it may be removed from the hydrogeological system by a pumping well or it may be discharged to the earth's surface as a spring, a lake or stream. Groundwater supplies are recharged by precipitation or from wadis. Groundwater pumped by wells or discharged by springs may have been stored for thousands of years, or may have entered the aquifer quite recently (Driscoll, 1989).

Wells are used to pump groundwater from different aquifer formations to supply water for many different uses. When pumping starts in an unconfined aquifer, most of the water is removed from the vicinity of the well. With continued pumping, water is collected further from the well, lowering the groundwater level at a greater distance from the well and forming a wide depression cone.

Drawdown decreases with the distance from the well until at some distance, the groundwater level remains relatively unaffected by pumping. Drawdown in the well continues to increase slightly with pumping due to aquifer and/or pump efficiency. After many hours of pumping the water level would nearly stabilize. Eventually, it will reach the steady state condition. The resulting cone-like shape of the water surface is referred to as the cone of depression (Hantush, 1964).

The size and shape of the cone of depression is determined by the aquifer formation and the amount of water being removed from the aquifer. For example, domestic wells generally pump for short periods of time at low rates. This results in small cones of depression. Even low-yield aquifers often can be developed for domestic uses.

Irrigation and municipal wells typically have high pumping rates and operate for long periods. Some wells may be operated continuously for several months. Aquifers must yield large volumes of water and hence much larger and deeper cones of depression result. In some cases, the cone of depression may extend several hundred feet from the well and be up to, or even more than, 91 meters deep. Where there are many wells, like in Wadies or major extraction sites (well fields), cones of depression for adjacent wells can overlap, increasing the depth and size of each well's cone of depression. Abstraction of water from an aquifer can also diminish the amount of outflow from a basin and eventually reduces stream flow downstream of the basin.

1.2.3. Groundwater recharge

Groundwater recharge is difficult to measure and must be well understood for the effective management of water resources. The two main mechanisms of natural recharge to regional aquifers in arid and semiarid areas are channel recharge and mountain front recharge.

While mountain front recharge is a vital component of the groundwater system in many of these areas, it constitutes only a minor fraction of the total amount of water delivered to the area by precipitation and therefore cannot be estimated reliably by "gross" water balance calculations. Estimates of mountain front recharge to regional aquifers are required for management purposes, particularly in order to determine the safe yield from wells in groundwater basins where overall recharge is small and development may readily lead to overdraft conditions. Such basins are common in arid and semiarid regions. Estimates of mountain front recharge also provide prescribed flux values for digital models of regional groundwater flow.

Prior estimates of mountain front recharge can be obtained with the aid of environmental isotopes and hydrochemical mass balance calculations. Another approach for the estimation of mountain front recharge is through the use of hydroclimatic models. Such models are particularly useful in areas where reasonable records of rainfall and streamflow exist and groundwater data is missing (Bear, 1979).

With the development of water wells, the natural balance between recharge rates and discharge rates is disrupted. The overall groundwater supply might be depleted due to increased discharge.

Depleted aquifers can be recharged by different sources. Alluvial and bedrock aquifers are either directly recharged from precipitation or indirectly by infiltration of surface runoff. Sub-surface flow from the Samail Ophiolite, Hawasinah units and Tertiary limestones also contribute to recharge alluvial aquifers of the upper catchments and the coastal aquifer of the Batinah plain. Leakage from overlying or adjacent shallow alluvium could be another source of recharge to bedrock aquifers.

Artificial recharge from dams is one of the important techniques that have been used to recharge the groundwater aquifers. Within the framework of an integrated plan to enhance the groundwater recharge in various areas of the sultanate of Oman, a recharge dam has been built in the lower catchment of Wadi Al-Jizzi across the main wadi channel.

1.3. Water Resources in the Sultanate of Oman

Oman is an arid country with hot climate and scarce rainfall. The rainfall varies from less than 50 mm in central Oman to over 300 mm in the Northern Oman Mountains (MWR, 1995). Figure 1.3 shows the annual rainfall in the country. Exploiting the available water resources in the past varied from one region to another. Aflaj systems were introduced in Oman about a thousand years ago and were used in irrigation. In Falaj system, water is tapped at the water table in mountains and in wadis and led by man-made subterranean channels or by channels that skirt and cling to mountain sides to areas of settlement. The water is used for irrigation and domestic purposes. At the coastal regions water for irrigation was obtained from wells using animal power.

The introduction of modern methods of extracting subterranean sources of water and the subsequent increase in the areas under cultivation have upset the long-existing balance between availability and utilization of water resources. Diesel and electrical pumps have replaced animal power for raising water from wells. Other pressures on available water resources arise from increasing agricultural productivity, increasing demands for developing industrial sector which was previously non-existent and mounting demands for domestic water as population and living standards rise. Groundwater over-

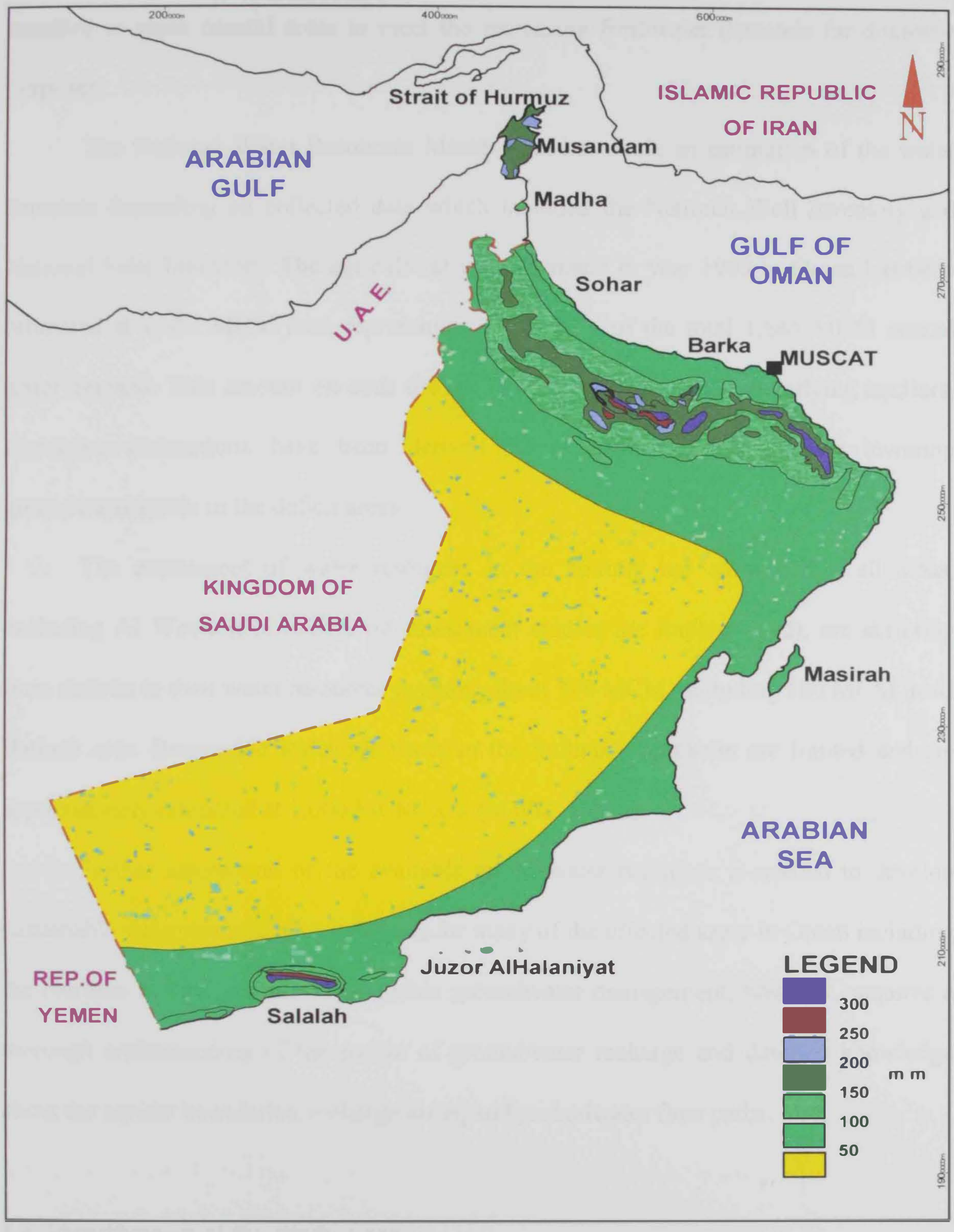

Figure 1.3. The annual rainfall isohyets in the Sultanate of Oman

exploitation and over-pumping practices have caused a remarkable increase in the water salinity due to decrease in groundwater levels. Desalination plants have been recently installed in some coastal areas to meet the increasing freshwater demands for domestic purposes.

The National Water Resources Master Plan has made an estimation of the water demands depending on collected data which included the National Well Inventory and National Falaj Inventory. The agricultural water demand in year 1995 in Oman has been estimated at 1,487 MCM/year, representing about 91% of the total 1,645 MCM annual water demand. This amount exceeds the sustainable resource of the underlying aquifers. Excessive abstractions have been derived from aquifer storage through lowering groundwater levels in the deficit areas.

The assessment of water resources in the country has showed that all areas, excluding Al Wosta area (where no assessment studies are implemented), are suffering from deficits in their water resources reaching about 378 MCM, including 180 MCM in Al Batinah area. Renewable water resources in the Sultanate of Oman are limited and are approximately estimated at 1,000 MCM/year (MWR, 1999b).

Further assessment of the available groundwater resources is needed to develop sustainable water management strategies for many of the affected areas in Oman including the Northen Batinah Region. Sustainable groundwater management, however, requires a thorough understanding of the nature of groundwater recharge and detailed knowledge about the aquifer boundaries, recharge areas, and groundwater flow paths.

1.4. Identification of the Study Area

Because its importance to the national economy, the Batinah area has been selected to constitute the subject matter of the study. The Batinah Region is the area between the sea and the mountains running from the border with the UAE to Muscat, Figure 1.4. Traditionally, this area was a fishing and farming region. Now it is becoming more commercial and industrialized area. It is one of the most densely populated areas of Oman.

By the mid-1980s, the water table along Al Batinah coast dropped significantly and the salinity of wells increased, affecting the groundwater quality. This was caused by the combined effect of cultivating lands close to the sea and pumping more groundwater than was being naturally recharged, thereby accelerating the seawater intrusion process. The Batinah coastal plain extends 270 km along the Gulf of Oman where most of the agricultural development occurs. In this area, shallow wells are used to irrigate crops such as date, lime, mango, alfalfa and other vegetables. Behind Batinah stretch the Western Hajar Mountains run parallel to the coast with highest peaks reaching over 3000 m (JICA, 1985).

One of the largest catchement areas in the north of the Batinah among the other 20 major catchement areas, is Wadi Al-Jizzi, which is located in Sohar town about 245 km north-west of Muscat, Figure 1.5. It consists of: i) an upper mountains catchement area on the Hajar Gharbi mountains; and ii) a lower catchement on the Batinah plain. The principal Wadis that drain to Waddi Al- Jizzi are: Wadis Kitnah, Ghalil, Hayl, Lasail, Barghah, and Yanbu. The total drainage area of Wadi Al-Jizzi is about 1050 km^2.

Development in Wadi Al-Jizzi catchment occurs mainly on the coastal plain between the main highway and the Gulf of Oman. Agriculture activities have increased in the last 3 decades due to the introduction of irrigation pumps and modern farming techniques. Recent preliminary assessments show a significant water deficit associated with saltwater intrusion. Wadi Al-Jizzi Dam was built in 1989 with a total reservoir capacity of 5.40×10^6 m^3 to recharge the aquifer of Wadi Al-Jizzi (Cansult, 1998).

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Figure1.4. The Batinah Area location map

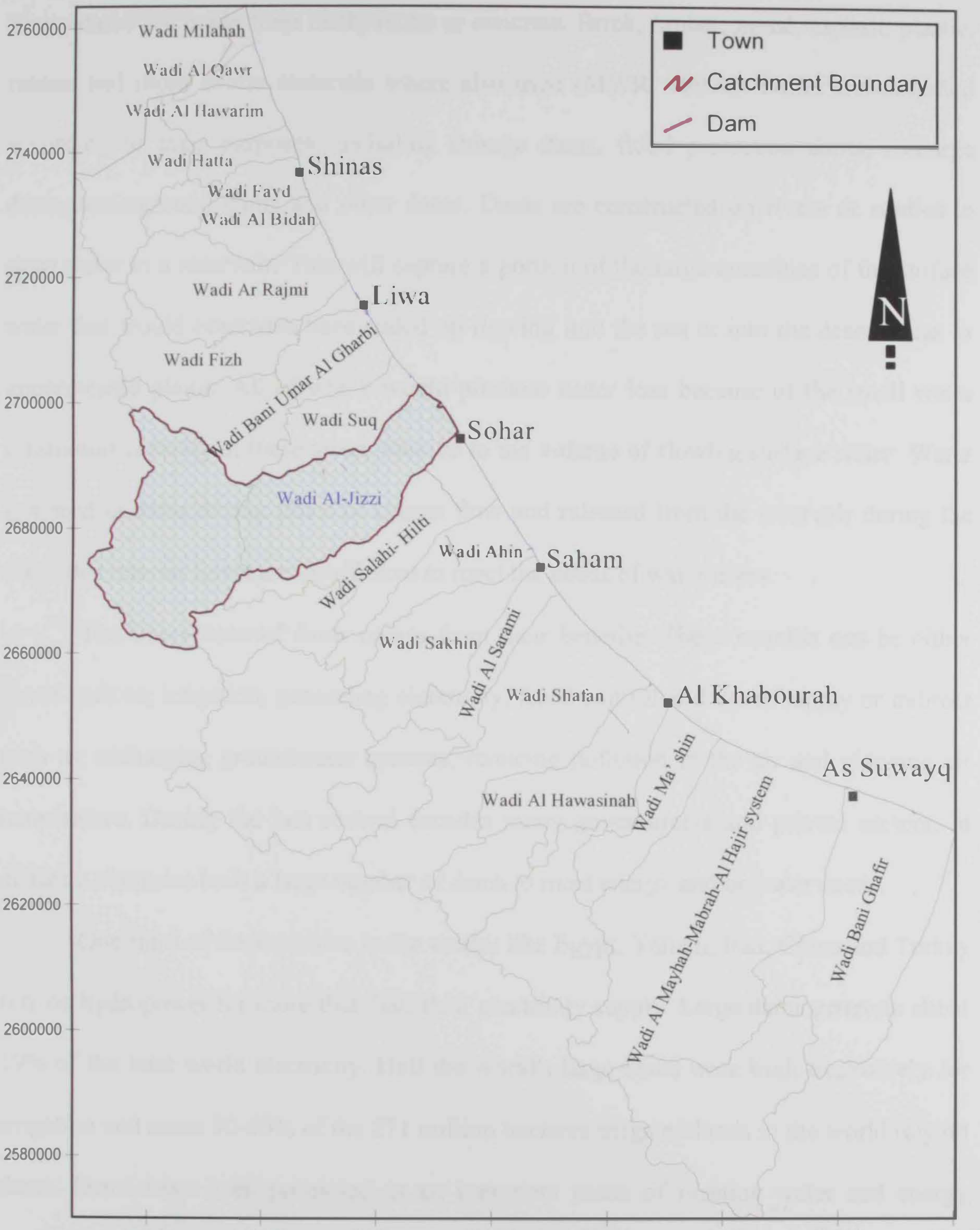


Figure 1.5. Northern Batinah catchments map

1.5. Water Harvesting through Dams

Several dams have been built for thousands of years in different countries of the world. These dams are made from earth, rocks or concrete. Brick, timber, metal, asphalt, plastic, rubber and more exotic materials where also used (MWR, 1999a). Dams are classified according to their purposes; including storage dams, flood protection dams, recharge dams, underground dams and other dams. Dams are constructed on rivers or wadies to store water in a reservoir. This will capture a portion of the large quantities of the surface water that would otherwise have ended up flowing into the sea or into the desert areas or impermeable plains. All of which would promote water loss because of the small water infiltration capacity in these areas, relative to the volume of flowing surface water. Water is stored in dams during times of excess flow and released from the reservoir during the times that natural flows are insufficient to meet the needs of water users.

The importance of dams comes from their benefits. These benefits can be either direct such as; irrigation, generating electricity, flood control and water supply or indirect such as; recharging groundwater systems, reducing pollution in the air and reducing air temperature. During the last several decades many governments and private sectors, in different countries built a large number of dams to meet energy and/or water needs.

One-third of the countries in the world; like Egypt, Yemen, Iran, China and Turkey rely on hydropower for more than half their electricity supply. Large dams generate about 19% of the total world electricity. Half the world's large dams were built exclusively for irrigation and some 30-40% of the 271 million hectares irrigated lands in the world rely on dams. Dams have been promoted as an important mean of meeting water and energy demands on the long-term and for strategic investment with the ability to deliver multiple benefits.

Dams were constructed in Several Arab countries since 1958. Many dams were built during the last three decades in the United Arab Emirates, Saudi Arabia, Oman, Syria, Lebanon and Jordan. The current groundwater recharge projects in these countries range from large productive projects contributing to the water reserve of groundwater aquifers used for drinking water supply and irrigation, to experimental projects for local testing and assessment of the groundwater technology as a mean of determining whether to approve or disapprove its use in specific situations (Linsley, *et al.* 1992).

1.6. Completed Dams in the Sultanate of Oman

Two types of dams were constructed in Oman, storage dams and recharge dams. Storage dams have been designed to store water during times of excess flow, so that water can be used when there is a lack in natural flow for irrigation and domestic uses. Recharge dams have been designed and built to store the surface runoff caused by rainfall and surface runoff in order to facilitate its infiltration to the subsurface and enhance the storage capacity of the aquifer. Figure 1.6 shows a general layout of a recharge dam. Flood water is stored in reservoirs upstream of the dams and then released under control to recharge the groundwater systems at the down stream side. Recharge dams are very important in performing a flood protection function, which can safe life and properties from damages.

It is estimated that about 120 MCM of water is lost to the sea or is evaporated in Oman (MWR, 1999b). This is regarded as a very significant water loss with consideration of the dry environmental conditions prevailing in the country. Artificial recharge is one of the most effective techniques to increase the availability of groundwater resources in Oman. There are several benefits of using artificial recharge methods including, among others, high groundwater storage capacity comparing to any surface structures, relatively cheap, water supplies are naturally purified for drinking purposes, evaporation losses are

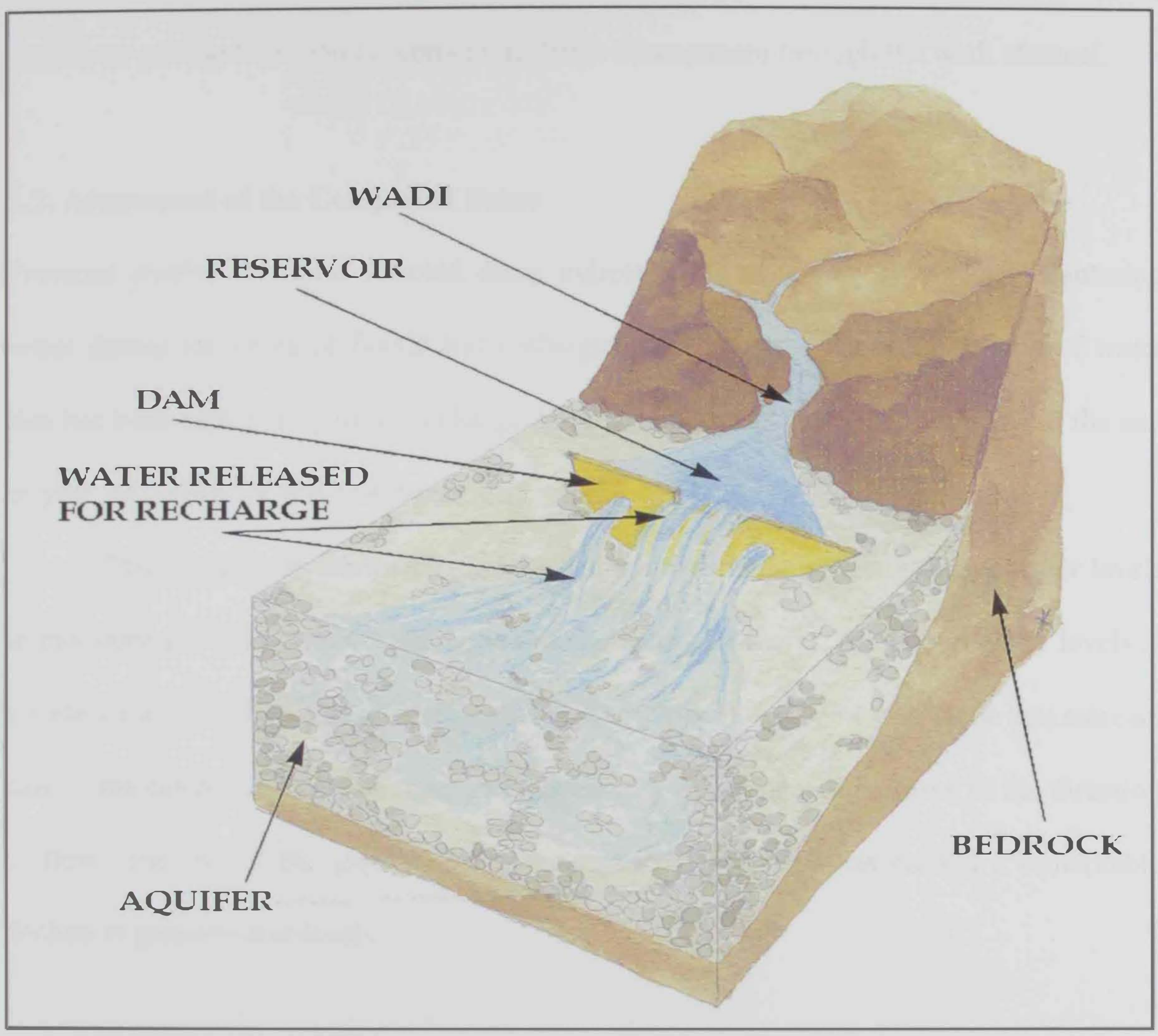


Figure 1.6. Recharge dam illustrations diagram

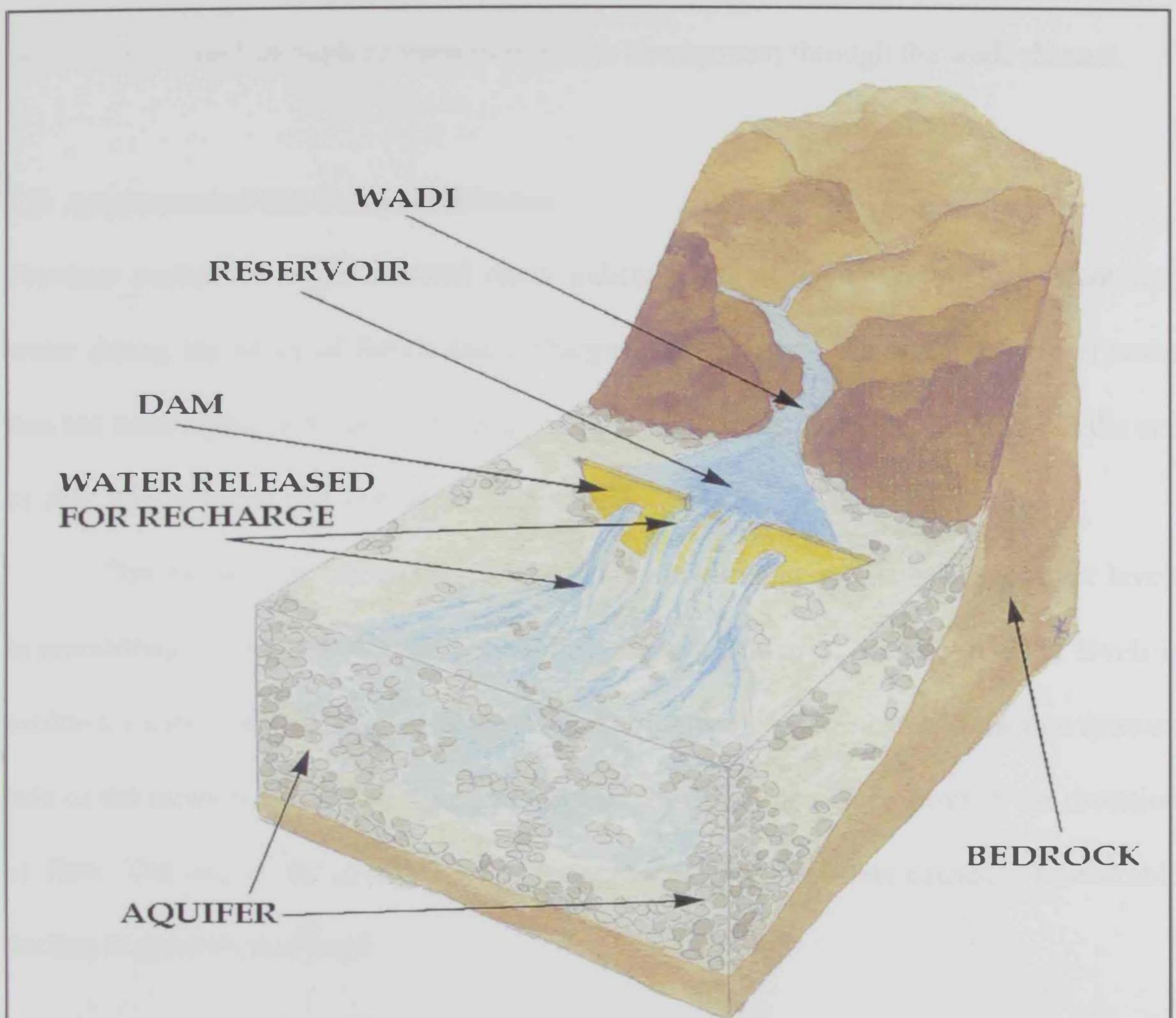


Figure 1.6. Recharge dam illustrations diagram

minimized and reduction of seawater intrusion in coastal areas; like in Al Batinah Plain, is achieved.

To that end, eighteen dams have been built since 1985 to recharge the groundwater systems and minimize the seawater intrusion in different areas of Oman (Table 1.1). The water that is held by the dams is either infiltrated from the reservoir to the underlying aquifer or released through culverts to infiltrate downstream through the wadi channel.

1.7. Assessment of the Completed Dams

Previous studies on some selected dams indicated the efficiency of dams in capturing water during the times of floods and recharging the aquifers. The total volume of water that has been captured by the18 recharge dams in Oman was about 727.5 MCM till the end of year 2003 (MRMEWR Database), Figure 1.7.

This can also be shown directly from the measurements of subsurface water levels in monitoring wells at the upstream side of the dams. However, the rise in water levels is visible for a short time due to the excessive pumping from wells located at the downstream side of the catchment. Also, the groundwater hump would generally move in the direction of flow. The use of the groundwater for agriculture purposes has caused a remarkable decline in groundwater levels.

1.7.1 The dam of Wadi Al-Jizzi

Wadi Al-Jizzi dam is one of the dams that have been built in Oman in the Batinah area near the foothills at the confluence of Wadi Al-Jizzi and Wadi Alawina. The dam was built to capture a significant part of flood flow that would otherwise drain to the sea. The volumes of water captured by Wadi Al-Jizzi per year from 1989 till 2003 are shown in Figure 1.8. The total volume of water that has been captured till the end of year 2003 was

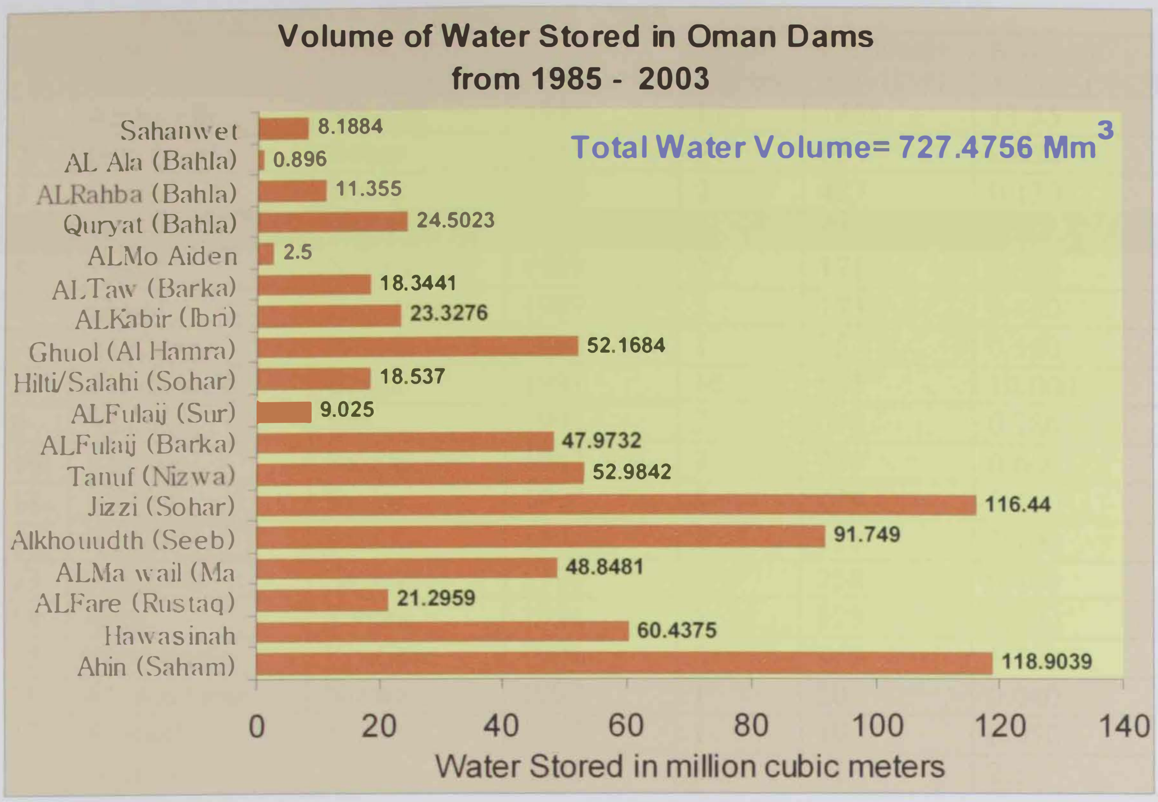


Figure 1.7. Total volume of water captured by dams in Oman from 1985 to 2003

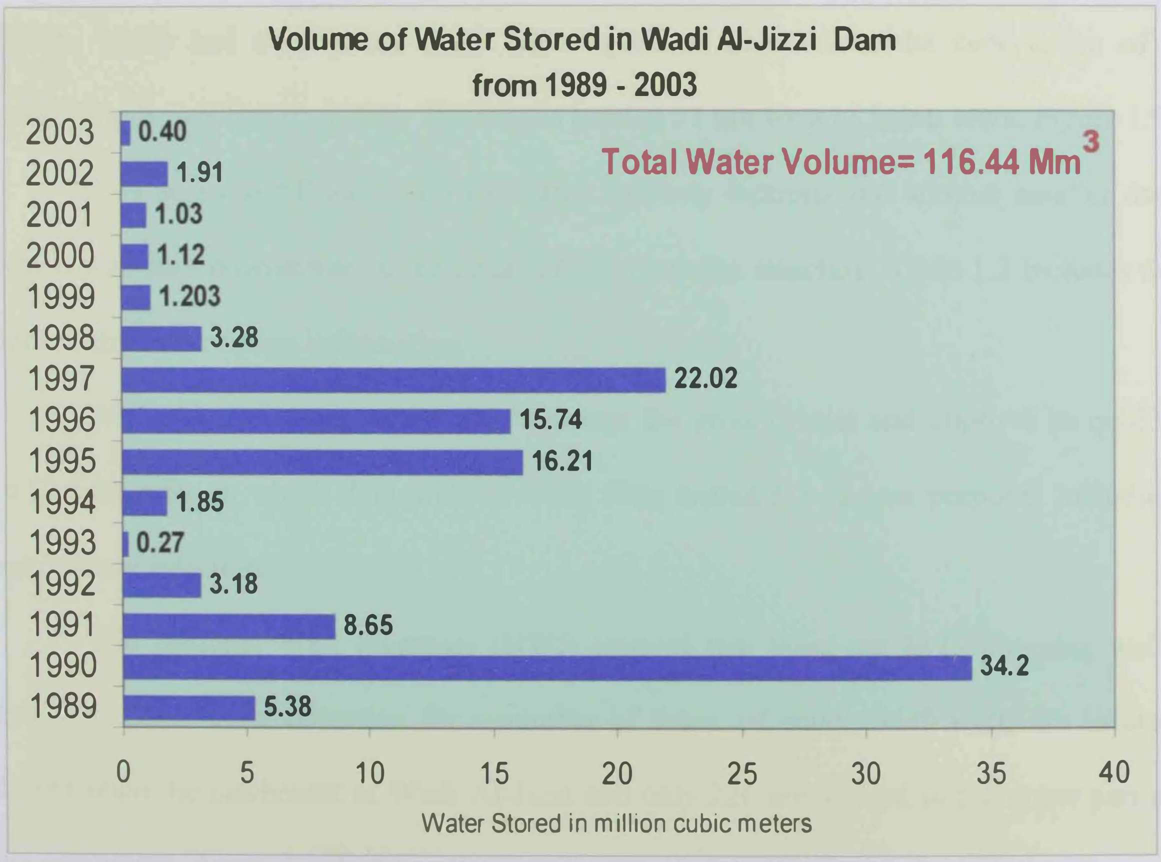


Figure 1.8. Volume of water captured by Wadi Al-Jizzi dam from 1989 to 2003

Table 1.1. Recharge dams in the Sultanate of Oman

No	Dam	Area	Year of Completion	No of Culvert	Catchment Area (km^2)	Reservoir Volume (MCM)
1	Alkhoudh	Muscat	1985	11	1635	11.55
2	Hilti/Salahi	Sohar	1985	31	554	0.550
3	Quryat	Bahla	1986	2	427	0.130
4	Jizzi	Sohar	1989	2	816	5.400
5	Tanuf	Nizwa	1989	2	171	0.680
6	Ghuol	AL Hamra	1989	2	173	0.450
7	ALKabir	Ibri	1991	1	757	0.500
8	ALMa wail	Barka	1991	10	555	10.000
9	ALFulaij	Sur	1991	2	677	0.780
10	ALFare	Rustaq	1992	2	209	0.600
11	ALTaw	Barka	1992	8	259	5.100
12	ALFulaij	Barka	1992	2	118	3.700
13	Sahanwet	Salalah	1993	3	258	6.400
14	Ahin	Saham	1994	5	829	6.800
15	Hawasinah	Khabura	1994	5	869	3.700
16	AL Ala (sent)	Nizwa	1997	1	20	0.040
17	ALRahba	Nizwa	1997	1	19	0.050
18	Wadi Muaydin	Nizwa	2002	5	313	2.5

116.44 MCM. The dam was designed by the Japan International Cooperation Agency (JICA, 1986) and constructed by J and P (Oman) LLC under the supervision of a consulting firm (Cansult, 1996). The dam is located 23 km west of Sohar town, Figure 1.9.

It is an earth fill dam with two large spillway sections and another smaller dam which was built downstream to serve as a flow diversion structure. Table 1.2 includes the construction and design information.

Wadi Al-Jizzi dam was built to recharge the groundwater and improve its quality in Batinah area, in which thousands of wells were drilled for various purposes including agricultural activities.

The National Well Inventory (NWI) showed that there are 3875 pumping wells that have been under operation for a number of years, of which 3649 wells are located downstream the catchment of Wadi Al-Jizzi and only 226 are located in the upper part of the catchment. Appendix A shows the distribution of operational and abounded wells over the catchment of Wadi Al-Jizzi.

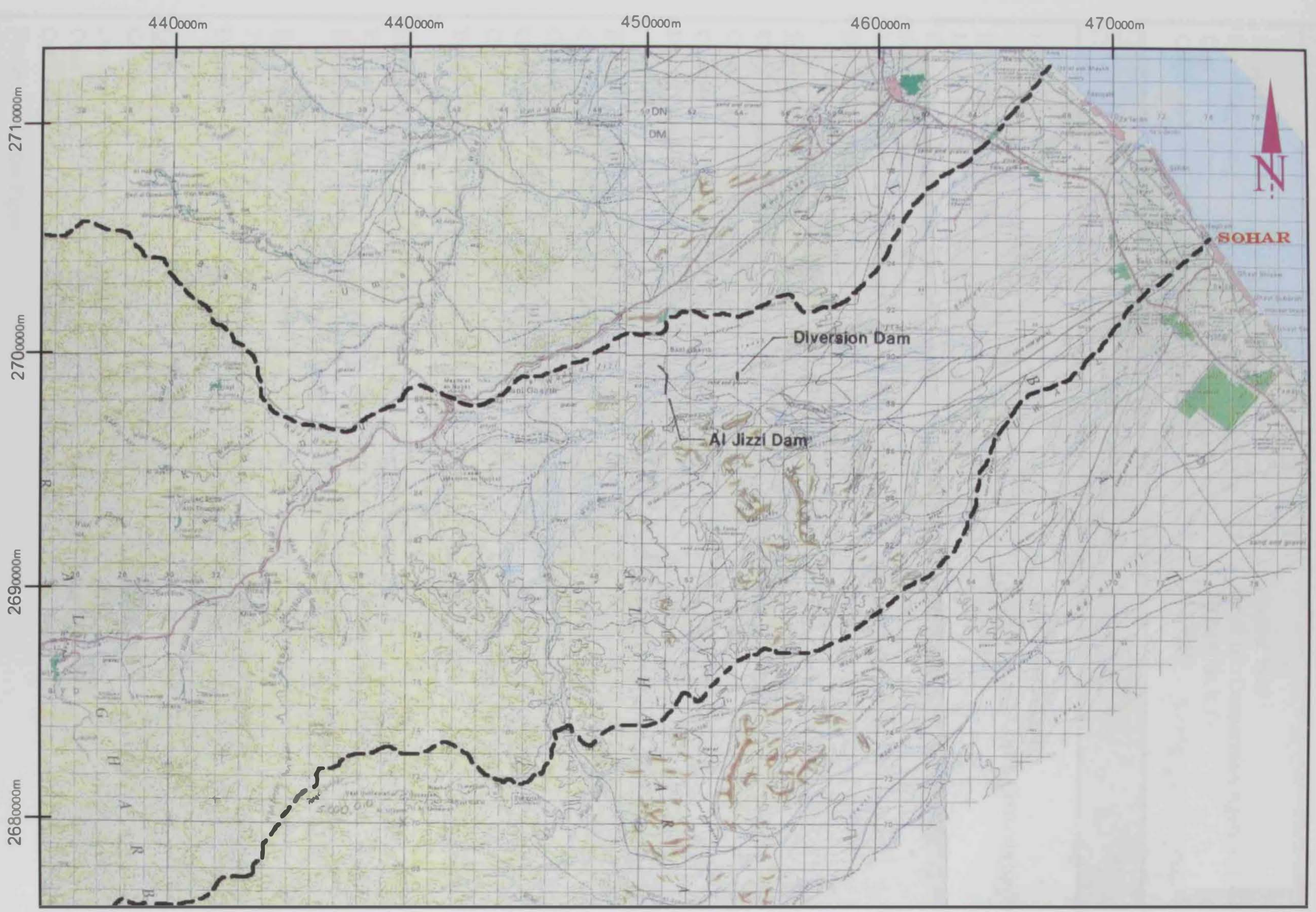


Figure 1.9. Topographic map of Wadi Al-Jizzi catchment area (Cansult, 1996)

Table 1.2. Construction and design information of Wadi Al-Jizzi recharge dam (Cansult, 1996)

General Data	
Completion Date	August 1989
Feasibility Study	Japan Int. Cooperation Agency (1986)
Cost	2.7 Million R.O.
Catchment Area	812 km²
Engineering Details	
Dam Construction	Zone Type Fill Dam
Spillway Type	Non-Controlled Open Concrete Spillways
Maximum Dam Height	20.4 m
Length of Dam Crest	1234 m (including spillways)
Elevation of Dam Crest	170.0 mASL
Reservoir Capacity	5.40×10^6 m³
Maximum Probable Flood	7800 m³/s
Discharge Canal	Unlined Open Channel
Service Spillway	
Crest Length	184 m
Crest Elevation	163.9 mASL
Crest Height	2 m
Design Flood Discharge	4700 m³/s
Emergency Spillway	
Crest Length	278 m
Crest Elevation	165.7 mASL
Crest Height	1.8 m
Crest Level	165.7 mASL
Design Flood Discharge	3100 m³/s
Main Outlet Pipe	
Type	Ungated Steel Pipe
Diameter	1.5 m
Emergency Outlet	
Type	Gated Steel Pipe
Diameter	1.5 m
Dispersion Dam	
Construction	Rock-Filled Gabion Dike
Distance Downstream from Main Dam	3.3 km
Crest Length	243 m
Crest Height	3.7 m
Number of Outlet Pipes	3
Outlet Pipe Diameter	1.2 m

According to the feasibility study conducted by the Japan International Cooperation Agency (JICA, 1986), Wadi Al-Jizzi dam is estimated to conserve about $3.5x10^{6}$ m^3/yr of surface water runoff from discharging to the sea. This amount is added to the groundwater and might be used to supply additional water for new agricultural development and to stabilize the groundwater conditions in the Sohar area (JICA, 1986). The additional recharge would also potentially benefit the municipal wellfield near Sohar and aflaj systems of the Batinah plain.

Like other dams in Oman, one of the most important problems in Wadi Al-Jizzi dam is the accumulation of silt in the reservoir which significantly decreases the rate of water infiltration down to the groundwater and causes clogging of culverts. It is also noted that there is an excessive seepage that is encountered when the dam is filled with water. The Wadi Al-Jizzi dam is 19 m height and this high hydraulic head would create a good potential for seepage beneath the structure. This problem was studied by Sir Mott MacDonald and Partners in the year 1990. The geologic logs and pressure testing of the monitoring wells (GHJ-1 to GHJ-9 and OWJ-1 and OWJ-2) adjacent to the dam indicated the presence of a water loose in the sand and gravel zone below the partly cemented surficial material within a fomler Wadi channel (DGIA, 1992). Grouting was conducted in 1992 and, as a result, the permeability of this zone was reduced (DGIA, 1992).

Additional field work was conducted in 1998 to cut off the seepage beneath the main body of the dam and to prevent further loss of fine soil material in this area. The reservoir of the dam has not been completely filled with water since that time to determine if there is any significant seepage or not.

1.8. Objectives of the Current Study

The ultimate aim of this study is to assess the groundwater recharge and pattern in the area of Wadi Al-Jizzi dam. The specific objectives of the study include:

1- Study the hydrogeological system in the area of Wadi Aljizzi and determine the main hydraulic and hydrogeological parameters of the system.

2- Employ a numerical model to simulate the groundwater recharge and the flow pattern in the study area.

3- Evaluate the efficiency and the performance of Wadi Aljizzi recharge dam.

1.9. Methodology

1- Data of groundwater levels, location of observation and pumping wells, rainfall, salinity, wadi flow and storage in the dam have been collected.

2- Different software's have been used to plot hydrographs and contour maps that represent the change in groundwater levels in the period between 1981 and 2003. Salinity contour maps have also been prepared to reflect the situation of groundwater quality associated with groundwater decline.

3- A numerical groundwater model (MODFLOW) has been used to simulate the flow and levels of groundwater during the period 1985 - 2002. Prediction scenario from 2003 till 2020 is conducted to assess the situation of groundwater levels within this period.

4- Conclusions are made based on the results of the study and several recommendations are proposed to sustain the available groundwater resources.

1.10. Previous Studies

Several studies have been conducted in the area of North Batinah which comes across Wadi Al-Jizzi. Some other studies have been done at Wadi Al-Jizzi specifically. Gibb and

Partners (1976) conducted a study to determine the hydrological and hydrogeological conditions of Northern Batinah Plain and Jebel. The study included borehole logs, aquifer test results, and water quality data for Wadi Al-jizzi. IRI Research Institute (1978) did some field work and drilling to determine the aquifer properties in Wadi Al-Jizzi and WAdi Al-Hilti. The alluvium thickness was found to be between 50 m and 240 m.

Hydroconsult (1985) conducted an investigation to study the surface and groundwater hydrology in the Batinah Coastal Plain. The study was limited to the coastal plain zone. Cansult and Gartner Lee (1986) used isotopes to determine the age of groundwater and the source of recharge to the aquifer system. This study concluded that the shallow groundwaters are young (about five years old), while the deeper groundwaters in the lower chatchments were between 35 and 1000 years old. The mountains were identified as the main source of recharge to the coastal aquifer.

(JICA) Japan International Cooperation Agency (1986) conducted a study on the geology, hydrogeology, groundwater balance, seawater intrusion and water management. In the feasibility study report they estimated that the construction of recharge dam in Wadi Al-Jizzi would provide 3.5×10^{6} m^3 of groundwater recharge per year.

Syed (1991) presented a preliminary assessment of artificial recharge that deals with the performance of Wadi Al-Jizzi dam. The report estimated that about 8.4×10^{6} m^3 infiltrated over the period from 1989 – 1990. This estimation was based on the water balance analysis.

The Ministry of Water Resources, DGWRA (1995) conducted a project for water assessment of Wadi Al-jizzi and data compilation. The study included monitoring activities and a water balance assessment for North Batinah catchments including Wadi Al-Jizzi. The water supply situation in the upper catchments of Northern Batinah is more favourable than for the lower catchments. The Aflaj and wells in the upper catchments are able to meet recent and future domestic and agricultural demand due to the limited demand in those areas. The transmissivity in these catchments ranges between 150 to 7000 m²/d, storage coefficient ranges between 1×10^{-4} to 1×10^{-2} and the thickness varies between 50 and 150 m. The lower catchments demand of Northern Batinah was estimated for about 254.13 MCM/year.

Cansult (1996) completed an evaluation study for Wadi Al-Jizzi dam. The available monitoring data, physiography, geology, hydrology and hydrogeology information at the dam site and the whole catchment of Wadi Al-Jizzi were presented. Their work consisted of three main phases; Phase 1: data analysis, Phase 2a: water balance and steady state groundwater flow, Phase 2b: additional hydrologic modeling and simulation of transient groundwater flow and Phase 3: long term analysis of recharge dams. In this study a three-layered finite-difference groundwater flow model was developed for the Al-Jizzi catchment to simulate steady-state flow in the vicinity of the Al-Jizzi recharge dam. The model layers represented the upper portion of the bedrock aquifer and the sequence of Ancient to Recent alluvium which overlies the steeply dipping bedrock. Constant head boundaries were applied at the coast in Layer 1. No-flow boundaries were applied at catchment boundaries and at the freshwater/seawater (FW/SW) interface.

The RECHARGE module of the MODFLOW model was used to simulate the direct recharge from rainfall and indirect recharge from wadi losses as underflow across the western boundary. According to this study, the most noticeable effect of the dam was the increased water levels in the area between the dam and the gas pipeline (about 11 km downstream).

The primary design objective of the Al-Jizzi dam was to provide additional recharge to the lower catchment while the model indicated that the assumed rates of recharge from the dam were reasonable. However, the increase in water levels was largely offset by the increase of pumping. The simulations indicated that while recharge from the dam cannot balance the increased pumping at the coast, it still performs a vital role in preventing drawdowns in the area downstream of the dam. It is unlikely; however, that the overall goals of minimizing the water deficit and saltwater intrusion at the coast will be realized unless measures such as restriction on agricultural use in the lower catchment are introduced. It should also be noted that there is still some discharge to the sea from flash flood events. It was recommended to consider low cost measures such as check dams and spreading areas in the lower catchment to capture this water and direct it to the coastal areas where the needs are high.

The Ministry of Water Resources (1996) completed a study encompassing the National Well Inventory Project of Wadi Al-Jizzi. The project included an inventory of all the wells in Wadi Al-Jizzi catchment. Physical and chemical characteristics of the groundwater were identified. The total number of inventoried wells within Wadi Al-Jizzi was 4123. The upper catchment had 287 wells and lower catchment had 3836 wells.

The Ministry of Water Resources (1999b) completed a detailed study as part of a series of studies constituting the National Water Resources Master Plan for the Sultanate of Oman. The study contained the hydrological and hydrogeological aspects for all the aquifers located in Sohar, Shinas and Liwa. It included the water resources assessment for existing conditions and the integrated catchment management plan.

WS Atkins International (2002) completed a study on Sohar city wellfield that is used to supply drinking water to parts of the city. This wellfield, which is operated by the Water Department of the Sohar Development Office (SDO), comprises 8 production wells and is located in Wadi Al-Jizzi on a gravel plain area, south of Sohar city. Due to the existing large population and rapid development in the Sohar city area, groundwater use has increased. The city wellfield was evaluated in order to ensure that it can meet the projected future demand. Otherwise, additional production wells could be constructed. The groundwater quality was examined and possible sources of contamination that may affect the water quality for the existing and expanded wellfield were identified. All available geological and the hydrogeological data of Wadi Al-Jizzi were included in this study.

The current study covers the full area of the lower catchment of Wadi Al-Jizzi while previous studies covered only a part of it.

1.11. Organization of Thesis

This thesis is composed of five chapters. Chapter one elaborates the importance of groundwater resources in arid regions in general and Sultanate of Oman in particular. The general and specific objectives of the study are elaborated and some of the relevant studies that dealt with groundwater resources in Oman and groundwater modeling are presented. The importance of dams as a recharge tools are discussed. An overall assessment of completed dams including the Wadi Al-Jizzi is presented. All previous studies and investigations related to Wadi Al-Jizzi are reviewed.

Chapter two has been devoted to the stratigraphy, structures, climatic conditions and rainfall in the Batinah area. Geological formations and subsurface lithology are described. The aquifer in the study area, its hydraulic characteristics and yield, the confining system and movement of groundwater are discussed. The surface runoff and water flow in Wadi Al-Jizzi catchment are also presented. Aflaj system, which are regarded as the oldest traditional irrigation system in Oman have been briefly discussed.

Chapter three presents the local conditions and an identification of the study domain. Analyses of subsurface water levels before and after the construction of Wadi Al-Jizzi dam are presented. Groundwater levels over the period from 1982 to 2003 are included. The reliability and consistency of these data are discussed. An analysis of groundwater quality before and after the construction of the dam is presented. The different water uses have been elaborated. About 95% of the available water in the study area is consumed by the agriculture sector. The SDO municipal well field which is located within the study area is included in the discussions.

Chapter four is devoted to the numerical simulation of groundwater flow in Wadi Al-Jizzi using MODFLOW. The capabilities and limitations of the computer code are discussed and its different applications are elaborated. Date requirements "input" and model output are presented. The three types of boundary conditions, namely, no-flow, constant head and general head are elaborated. The model parameters, calibration process, and selected scenarios are discussed. The calibration, validation and prediction scenarios are elaborated. The comparison between observed and simulated groundwater levels is presented.

Chapter five includes the summary of all the work completed in the thesis. The conclusions of the study are presented and several recommendations for groundwater management and future studies are proposed.

Chapter 2. Geological and Hydrogeological Aspects

2.1. Stratigraphy and Structures

Oman is located in the southeastern margin of the Arabian plate close to the boundaries of the Iranian, Indian, and African plates. Consequently, plate movements have resulted in complex structural, sedimentation and burial histories. Oman is tectonically bounded on the south by the Gulf of Aden spreading zone, to the east by the Masirah Transform Fault and the Owen Fracture Zone Trough, and to the north by the complex Zagros-Makran convergent plate margin, compression along which produced the Oman Mountains. These variations in Oman's terrain lead to a distinction in its geological features that shape the landscape from one location to another. Figure 2.1 illustrates the idea of sea floor spreading and the formation of the oceanic crust leading to the drifting of the continents (Hanna, 1995).

Various types of rocks; igneous, metamorphic, and sedimentary, ranging in age from 800 million years to recent formations are encountered at different locations. The geology and structure of Oman are related to the formation of the Arabian Plate, which was submerged under a shallow sea. This leads to deposition of limestones and dolomites over most of Oman. Sediments of different ages were deposited on this plate and experienced a number of periods of folding and faulting (MWR, 1995).

The formation of the Hawasinah bed appeared when the north and east of the Arabian Plate and the Indian pushed into the oceanic part of the Asian Plate in the late Cretaceous period. The mantle and crust units, which were pushed upward in the Late Cretaceous, comprise together the Samail Ophiolite. The processes of uplift and erosion have produced the Northern Oman Mountains.

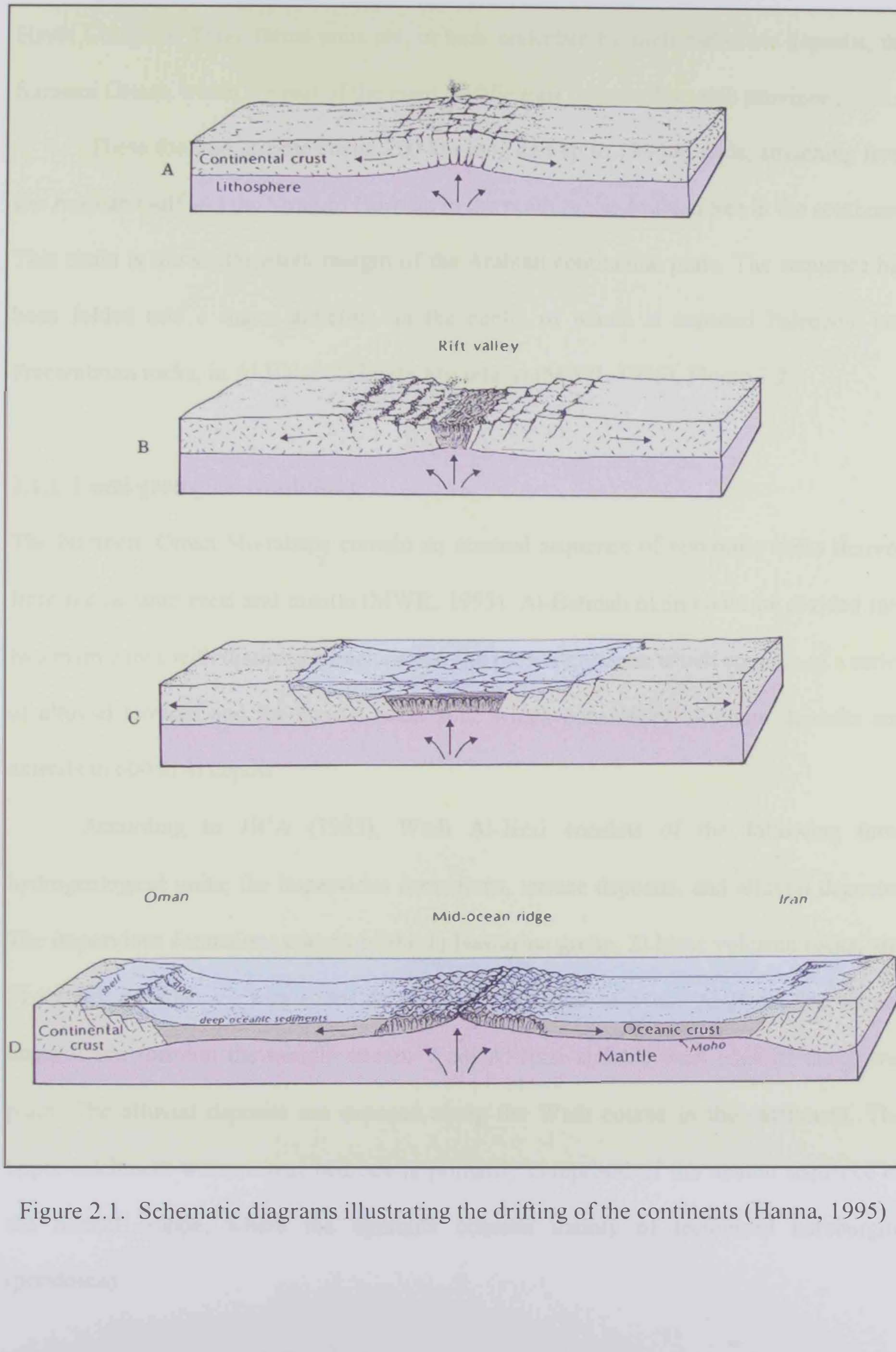


Figure 2.1. Schematic diagrams illustrating the drifting of the continents (Hanna, 1995)

Beneath the ophiolite lie complicated assemblages of deep-sea sediments, volcanics and melange, emplaced as thrust sheets, termed the Hawasina Complex and the Haybi Complex. These thrust units are, in turn, underlain by shelf carbonate deposits, the Sumeini Group, which are part of the giant Middle East hydrocarbon-rich province .

These form an arcuate chain, 700 km long and up to 120 km wide, stretching from the Arabian Gulf and the Strait of Hormuz in the north to the Arabian Sea in the southeast. This chain is the southeastern margin of the Arabian continental plate. The sequence has been folded into a major anticline, in the centre of which is exposed Paleozoic and Precambrian rocks, in Al Hajar al Gharbi Mountains (MWR, 1995), Figure 2.2.

2.1.1. Local geological conditions

The Northern Oman Mountains contain an unusual sequence of ophiolitic rocks derived from the oceanic crust and mantle (MWR, 1995). Al-Batinah plain could be divided into two main zones with distinct characteristics; the piedoment zone which consists of a series of alluvial terraces and the coastal plain zone which consists of alluvium deposits and extends to 600 m in depths.

According to JICA (1985), Wadi Al-Jizzi consists of the following three hydrogeological units; the impervious formations, terrace deposits, and alluvial deposits. The impervious formations consist of the 1) Hawasina group, 2) basic volcanic rocks, and 3) tertiary sedimentary formations forming the upstream of Wadi Al-Jizzi. The terrace deposits are forming the middle stream Wadi Al-Jizzi and the west edge of the gravel plain. The alluvial deposits are exposed along the Wadi course in the catchment. The upper catchment western part bedrock is primarily comprised of the mantle sequence of the Samail Nappe, where the ophiolite consists mainly of tectonized harzburgite (peridotite).

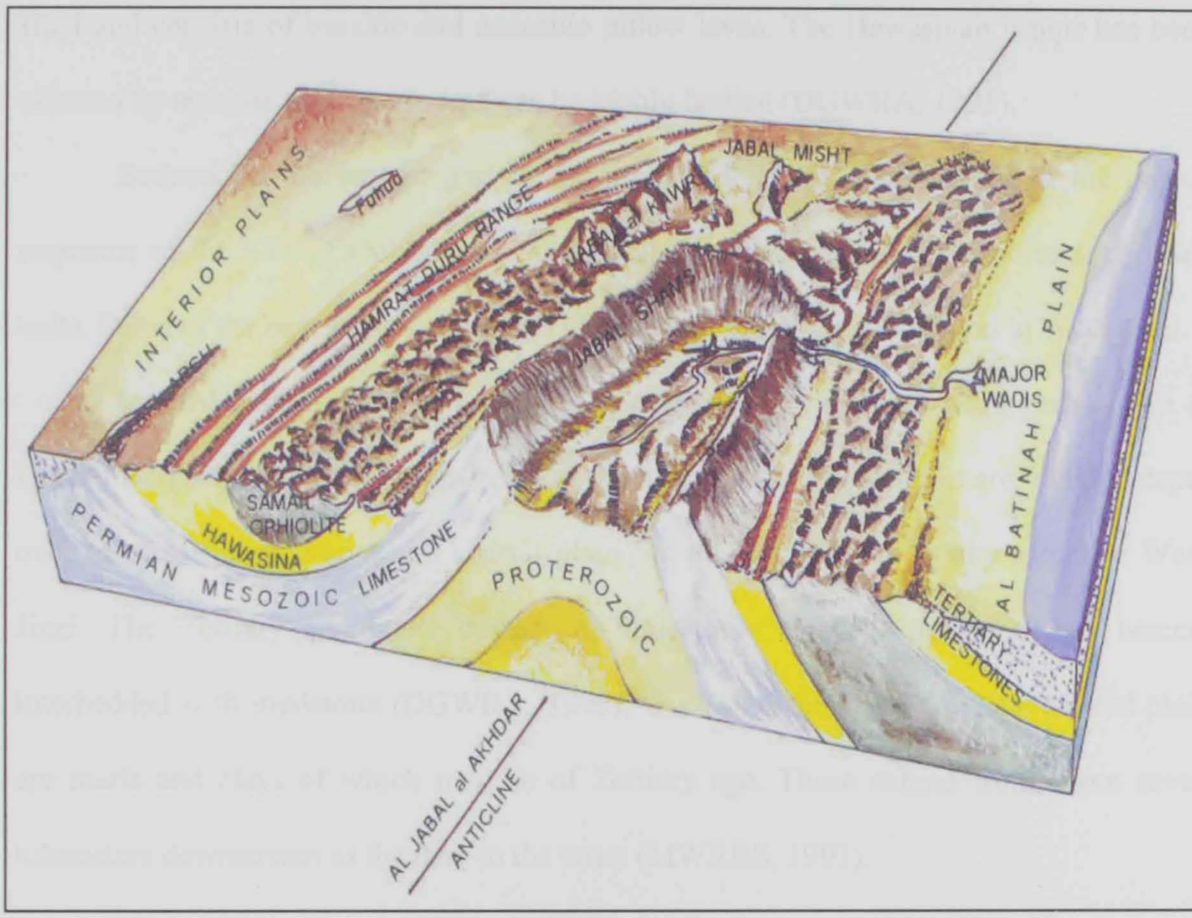


Figure 2.2. Al Hajar al Gharbi Mountains (MWR, 1995)

The Hawasina Nappe that forms the low hills in this part of the catchment is comprised of the Hamrat Duru Group and Umar Group. In Wadi Al-Jizzi, the lower member of the Mabat Formation (late Triassic) of the Hamrat Duru Group is exposed. It consists of radiolarian chert with some shale beds, Figure 2.3. The Sini Formation (Triassic) of the Umar group outcrops in the center of the valley near Al Wasit and near Hayl and consists of basaltic and andesitic pillow lavas. The Hawasinah Nappe has been affected by tectonic movements and can be highly faulted (DGWRA, 1995).

Bedrock in the eastern part of the upper catchment is comprised of the crustal sequence of the Samail Ophiolites. The crustal sequence consists of gabbros and basalt units. Some of the best known exposures of basaltic pillow lavas are found in Wadi Jizzi.

Isolated outcrops of Hawasina Nappe occur in the piedmont plain such as that at Hawrat Barghah about 1.5 km upstream of the dam. Tertiary limestones are found at depth over most of the piedmont and coastal plain but are not exposed to any extent in Wadi Jizzi. The Tertiary sediments consist of limestones, clayey limestone and breccia interbedded with mudstone (DGWRA, 1995). Overlying the bedrock in the coastal plain are marls and clays of which may be of Tertiary age. These extend from about seven kilometers downstream of the dam to the coast (MWRRS, 1993).

The alluvial deposits of Quaternary age overlie the bedrock or clays and marls, where present. These deposits consist of silts, sands, gravels and pebbles. The Quaternary deposits can be divided into very Ancient to Ancient alluvium and sub-Recent to Recent alluvium. The Ancient alluvial deposits are found at higher elevations and also underlie the sub-Recent and Recent alluvium. Ancient alluvium predominates in the upper catchment and in the western part of the piedmont plain. The deposits are generally coarser, consisting of sands and gravels, but are highly cemented. Recent and sub-Recent alluvium dominates in the coastal plain. The deposits consist of boulders, gravels and silty

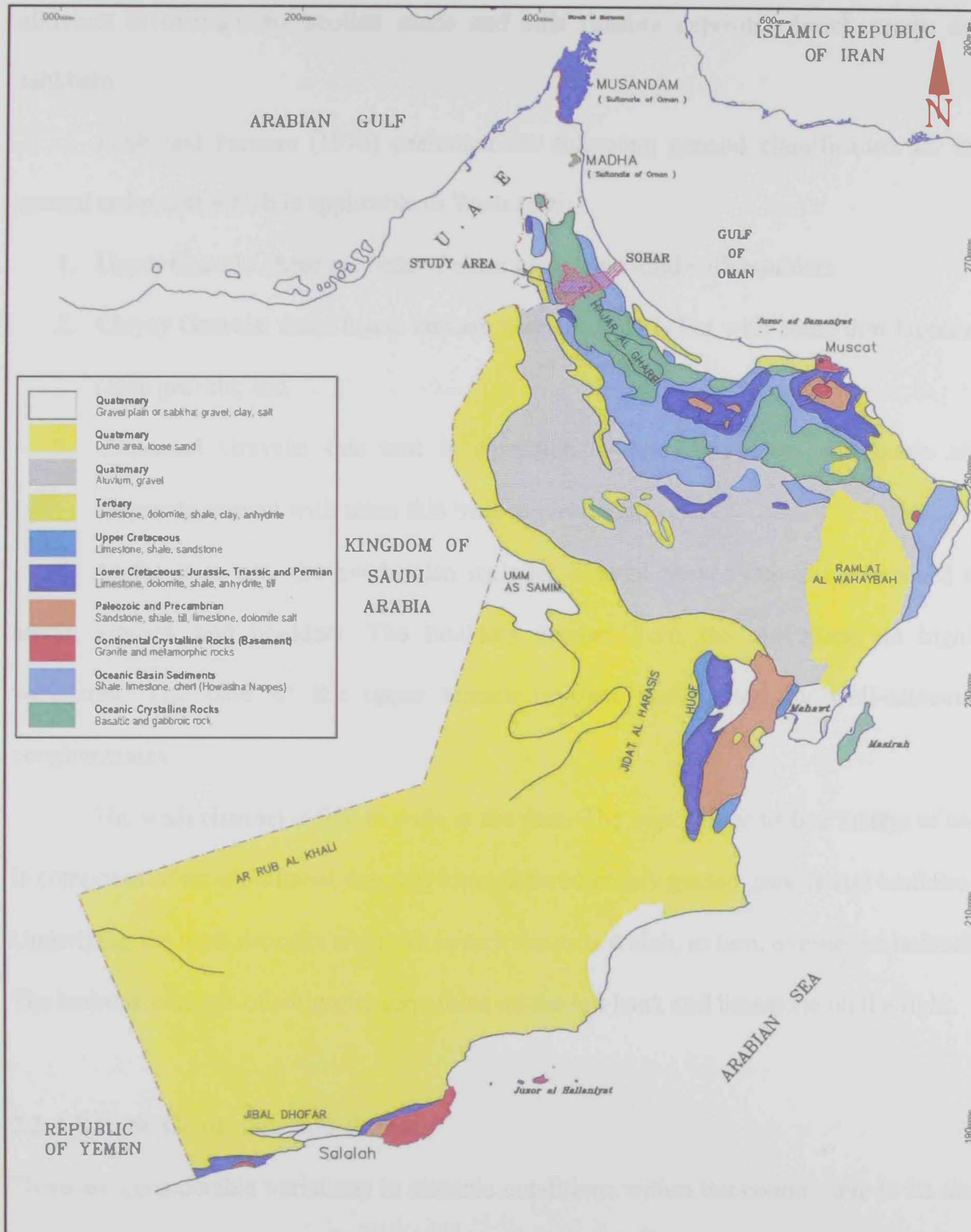


Figure 2.3. A Geological map of the Sultanate of Oman (GISS, MRMEWR)

sands of variable composition. The deposits generally become thicker and finer towards the coast and cover the terrace deposits. Between the highway and coast, the recent alluvium is overlain by aeolian sands and silts (khabra deposits), beach sands, and sabkhahs.

Gibb and Partners (1976) presented the following general classification for the coastal sediments which is applicable to Wadi Jizzi:

1. Upper Gravels: these are beds of clean gravel and sand with boulders
2. Clayey Gravels: these layers contain clays and marls but with some thin layers of clean gravels; and
3. Cemented Gravels: this unit is characterized by white clays and marls and carbonate cement with some thin beds of cleaner gravels.

At the dam site, the overburden includes alluvial terrace deposits composed of sands, gravels, and boulders. The boulders derived from the ophiolites are highly weathered. The base of the upper terrace deposits are formed by well-cemented conglomerates.

The wadi channel is 650 m wide at the dam. The upper three to five meters of soil is composed of recent alluvial deposits (unweathered poorly graded gravels and boulders). Underlying the wadi deposits are older terrace deposits which, in turn, overlie the bedrock. The bedrock consists of antigorite/serpentine on the left bank and limestone on the right.

2.2. Climatic Conditions and Rainfall

There are considerable variations in climatic conditions within the country due to its size and the configuration of its topography. The climate differs from one region to another. It is hot and humid during summer in the coastal areas and hot and dry in the interior regions with the exception of the high elevation lands and the southern Dhofar region, where the climate remains moderate throughout the year.

Rainfall is generally scarce and irregular. It varies from less than 50 mm in central Oman, rising to over 300 mm in the Northen Oman Mountains (MWR, 1995). The rainfall is regular only in the extreme south where the seaward facing slopes of the mountains and the coastal plains have the benefit of moderate summer monsoons extending from June to September. In the north of Oman, heavy and very localised thunderstorms occur over the Hajar range of mountains during the summer months, and in the winter occasional depressions sweeping across the Arabian Peninsula bring rain to the interior and coastal regions. Figure 2.4 shows the annual average rainfall in Wadi Al-Jizzi catchment area. It varies between 100 and 150 mm/year.

There are 10 rainfall gauges distributed in different sites over the upper and lower parts of the catchment. These gauges are used to estimate the amounts of rainfall in the Al-Jizzi catchment area and can be used to develop any realistic rainfall-flood relationships for the catchment. Locations of gauge stations are shown in Figure 2.5. Rainfall data of the different stations are presented in Appendix B.

The site ID for these stations are; Ubailah (DM173968AF), Qubair (DM268029AF), Kitnah (DM260958AF), Hayl near Wadi Al Jizzi (DM271711AF), Daqiq (DM264436AF), Hayl Adhah (DM382737AF and BF), Khan (DM383052AF), Farfar (DM374569AF), Laqaq (DM476902AF) and Jizzi Dam (DM580942AF).

The rainfall gauges, used in Wadi Al-Jizzi catchment area, are of different types; standard gauges (daily manually observed gauges), mechanical gauges and automatic gauges with continuous recording data.

The rainfall during the winter period (primarily in February and March) is due to depressions or low pressure systems moving southeastward from the Mediterranean Sea,

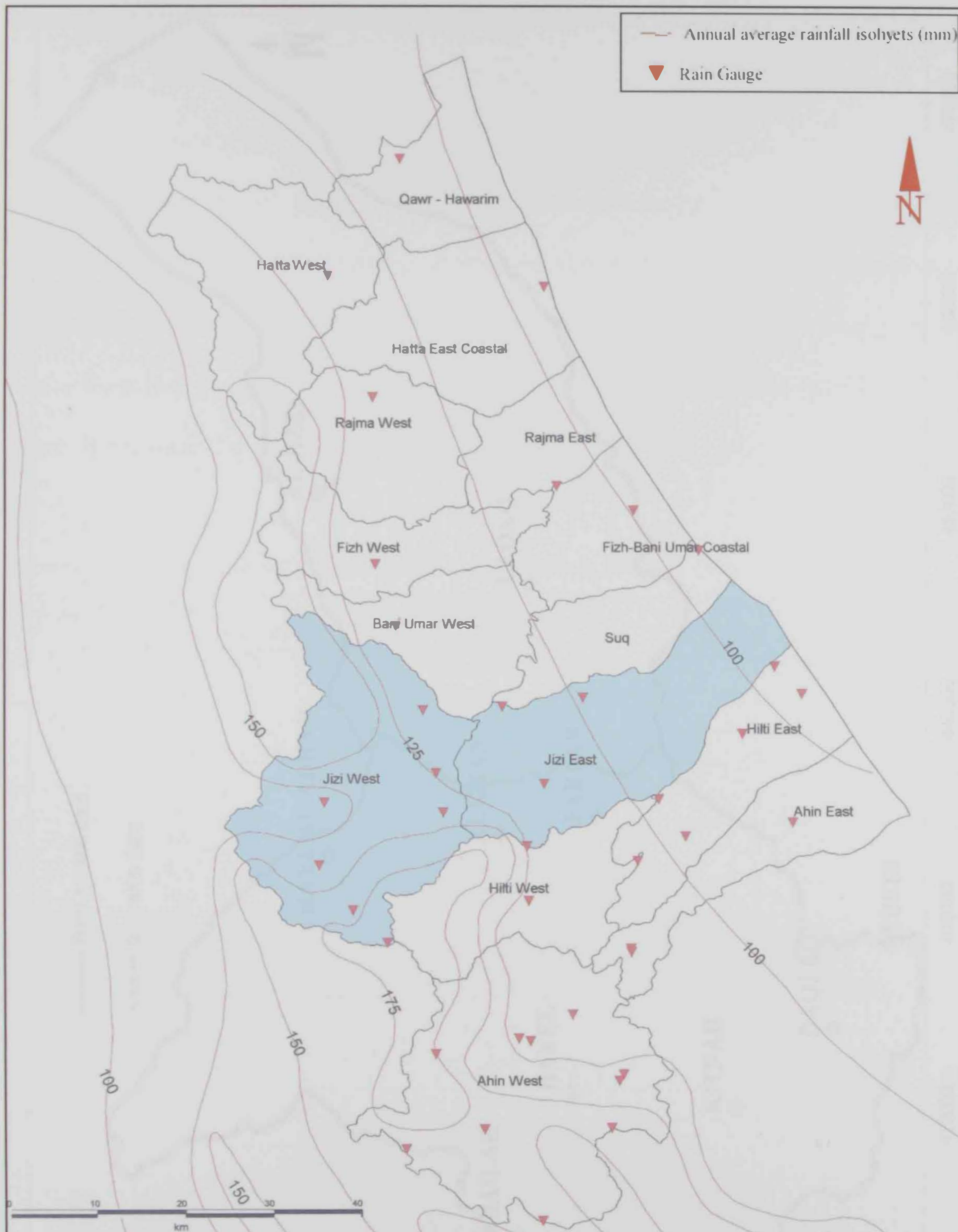


Figure 2.4. The annual average rainfall isohyets in Wadi Al-Jizzi (MWR, 1999b)

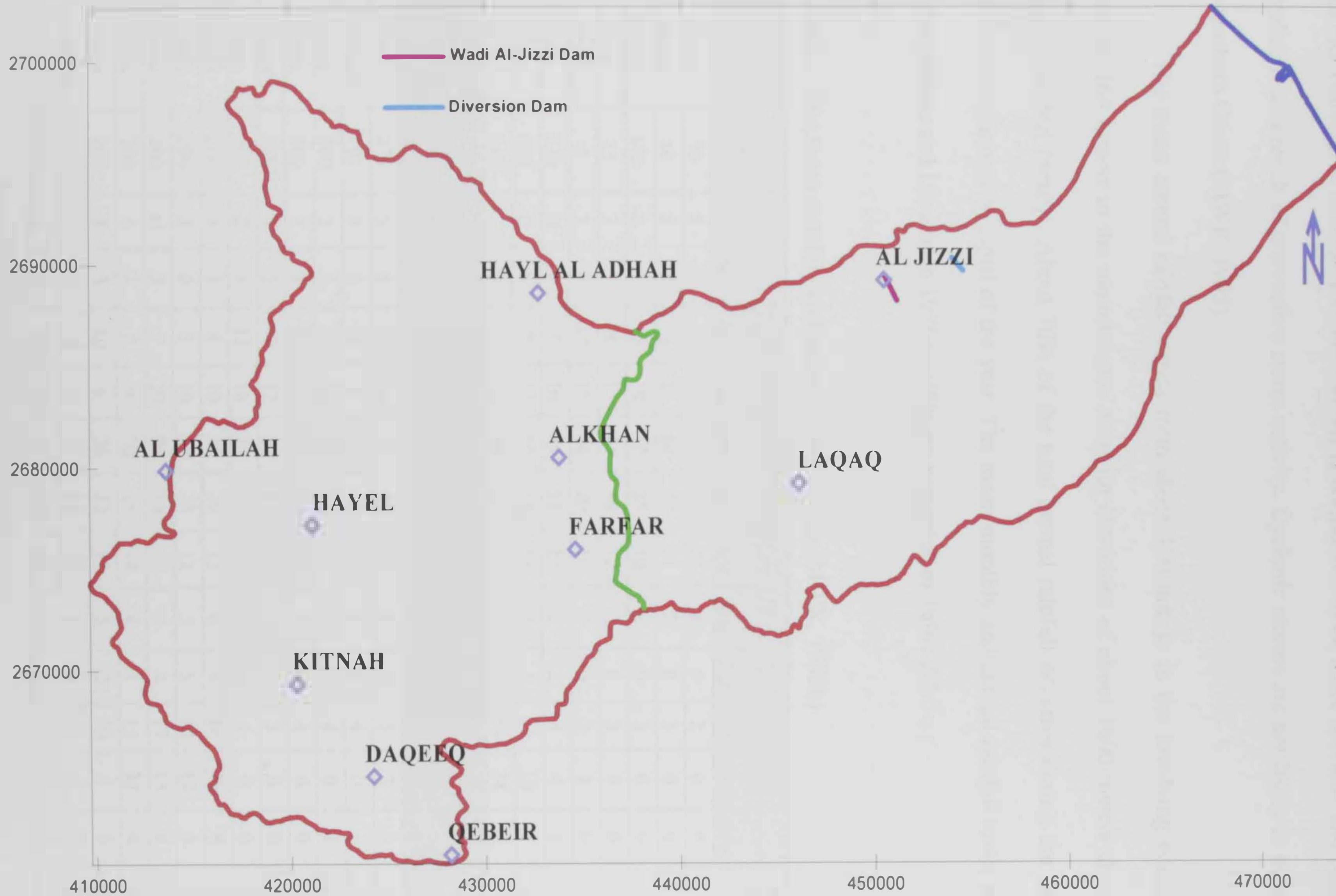


Figure 2.5. Rainfall stations location map in Wadi Al-Jizzi catchment

passing into Oman roughly parallel with the Northern Jebal Range. These events are generally larger in extent, of longer duration, but of lower intensity as compared to the summer convective storms. Summer rainfall is considered to be more sporadic and more localized, as a result of convective storm activity. Cyclonic storms are not likely to occur in northern Oman (MWR, 1995).

The mean annual rainfall varies from about 100 mm/yr in the low-lying coastal plain to 160 mm/yr in the mountainous areas (at elevations of about 1600 meters above mean sea level (amsl)). About 70% of the total annual rainfall occurres during the wet period from January to April of the year. The mean monthly and annual rainfall totals for Sohar, Shinas and Liwa from 1975 to 1996 are presented in Table 2.1.

Table 2.1. The mean monthly and annual rainfall totals (MWR, 1999b)

Station Name	Elev. m amsl	Average Monthly Rainfall for 22 Years 1975-96 - mm												Ann Av mm
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Aswad	70	2	3	16	12	44	33	13	1	0	2	0	0	126
Shinas	10	2	3	15	17	40	32	11	2	0	3	0	0	125
Sabakh	100	2	3	12	18	37	25	10	2	0	3	0	0	111
Liwa	15	3	3	20	15	44	19	12	2	0	3	0	0	120
Majis	4	3	3	13	15	44	20	10	2	0	2	1	0	113
Hayi	520	0	0	7	10	45	21	13	2	2	8	4	1	114
Kitnah	650	0	0	7	13	39	18	11	2	1	11	10	3	116
Daqeeq	840	3	0	7	16	40	23	15	3	5	34	24	11	180
Hayl al Adha	430	7	4	7	12	41	19	9	3	2	7	5	1	117
AL Khan	420	4	3	7	9	38	20	16	4	2	12	12	1	129
Far Far	620	4	6	5	7	41	19	18	4	3	11	13	2	134
OMC	275	5	2	12	16	42	22	11	2	2	5	3	0	124
Ar Rakah	197	4	3	11	9	34	14	15	1	1	4	0	1	97
Yanbu	200	3	3	13	10	42	16	13	2	1	4	0	1	107
Yanbu	200	2	4	8	7	34	14	13	3	2	4	6	0	98
Yanbu	200	3	2	12	12	39	17	11	1	0	3	0	0	102
Yanbu	200	2	1	12	16	39	20	11	1	0	4	0	0	107
Yanbu	200	3	1	4	10	32	29	13	6	6	16	18	8	145
Yanbu	200	3	0	5	10	29	23	12	5	5	13	12	4	122
Yanbu	200	11	3	2	10	29	19	12	5	4	17	15	9	136
Yanbu	200	4	1	7	9	30	15	14	4	1	13	12	4	114
Yanbu	200	4	3	10	6	26	12	11	3	2	10	4	3	94
Regional Average (mm)		3	2	10	12	38	21	12	3	2	9	6	2	120
Regional Average (%)		3	2	8	10	32	17	10	2	1	7	5	2	

2.3. Surface Water Runoff

Surface runoff constitutes an important source of water. It can be used directly or allowed to infiltrate through the soil to recharge the groundwater. The amount of surface runoff is determined by the intensity and duration of the rainfall. The wadi gauging stations in Oman record about 8 mm annual runoff in average (MWR, 1999a). Estimated mean annual runoff passing from the runoff producing zone to the runoff-absorbing zones to sea or desert is between one and 1.5 cubic kilometers, that is between one and 1.5 billion cubic meters (MWR, 1999a). There are two wadi gauges located in the study area (Wadi Al-Jizzi catchment). An automatic recording gauge in Wadi Al-Jizzi near Mulaynah (DB388507AD) is located about 10 km upstream of the Al-Jizzi Recharge Dam. Another automatic gauge is placed in Wadi Al-Jizzi near Sohar (DB698772AD). The locations of these two gauge stations are shown in Figure 2.6.

The records of the wadi flows since 1984 are both reliable and complete with exception of some short periods of lost data. Recorded annual wadi flows for the two above gauge stations have averaged about 15 MCM/yr and about 6 MCM/yr, respectively.

The surface water flow is mostly occurring between January and April which are regarded as the wet months (WS Atkins, 2002). These records are representative and could be used in the calibration and validation of numerical models.

2.4. Aflaj System

Aflaj were introduced into Oman about a thousand years back and were used to transport either groundwater or surface water. In Falaj system, water is tapped at the water table in the mountains and in wadis, and is led by man-made subterranean channels or by channels that skirt and cling to mountain sides to areas of settlement without any mechanical devices. The Aflaj water is used for irrigation and domestic purposes. Most of the old aflaj

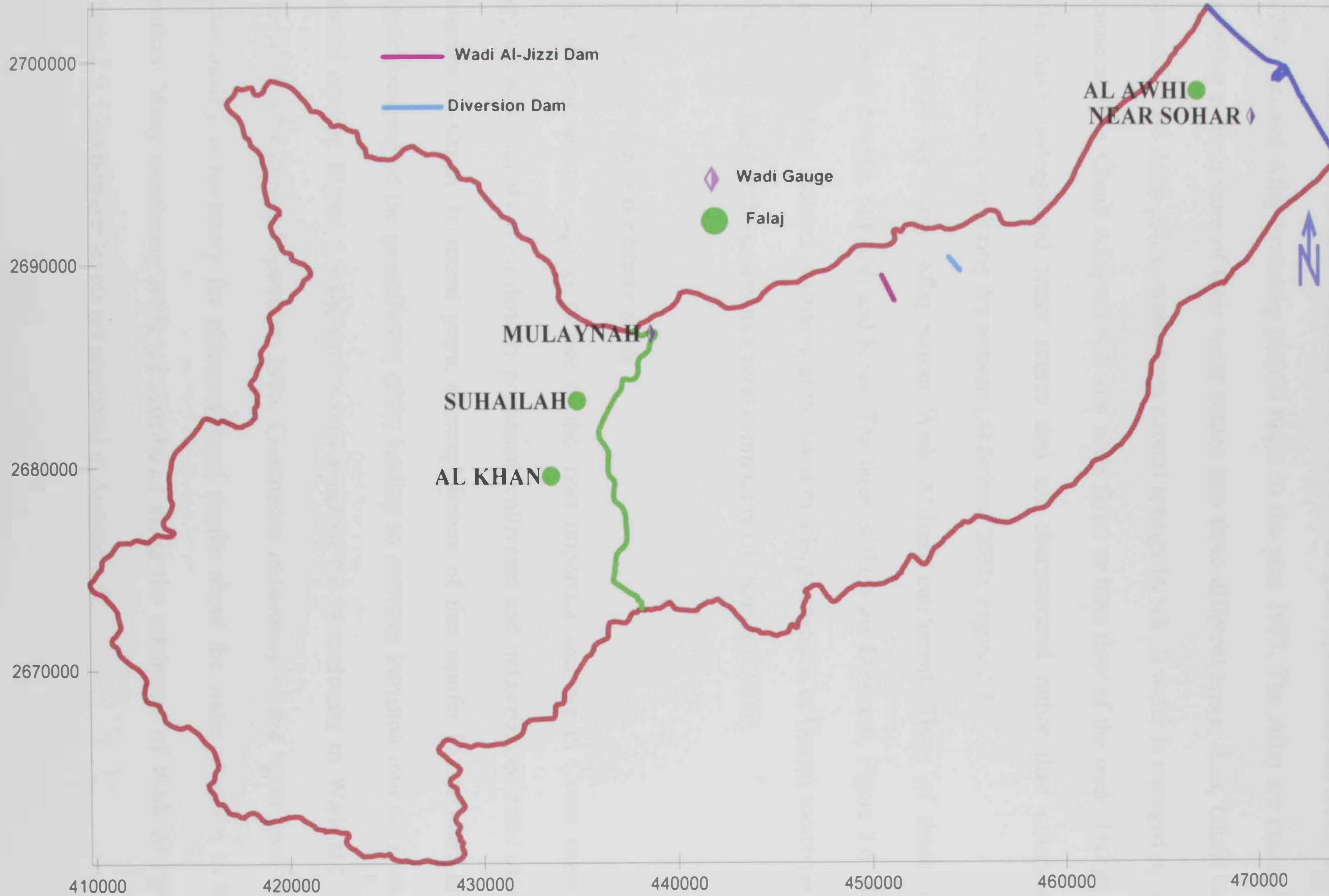


Figure 2.6. Wadi gauges and Aflaj location map in Wadi Al-Jizzi catchment

are made from Sarouj (Local word of an old material used in construction of Aflaj in the past) with different proportions of sand. Recent ones are made of concrete.

There are 4112 falaj in Oman, of which 3017 falaj are operational according to the MWR National Aflaj Inventory project made in the year 1997. The Aflaj are classified according to the nature of their water source into three different types; Aini, Ghaili and Dawoodi. Aini Aflaj collect water from natural springs by which water is emerged to the ground surface. Ghaili Aflaj are fed with wadi flows or base flow of the wadi. Dawoodi Aflaj have underground water source and are characterized rather than others by continuous flow even during dry seasons (Al Sarhani, 2000), Figure 2.7.

There are many Aflaj within Wadi Al-Jizzi catchment. Three of these are monitored: Alawhi, Suhailah and Khan. The three of them are Dawoodi, Figure 2.6. The threat to the falaj systems is striking at the basis of a large segment of Omani society, and at the major facet of the subsistence rural community (Al-Sarhani, 2000).

2.5. The Aquifer in the Study Area

The Batinah alluvial aquifer is one of the most important aquifers in Oman since it supplies water for the most densely populated, cultivated and industrialized areas of the Sultanate of Oman. In recent years, overexploitation of this aquifer has resulted in a drastic lowering of the groundwater table, leading to seawater intrusion into the coastal alluvial aquifer. Figure 2.8 shows the movement of the groundwater in Wadi al-Jizzi alluvial aquifer during September 1996. Continuous monitoring of the water level and water quality is necessary for obtaining good results about the water situation in the aquifers. Many monitoring wells are distributed along the catchment of Wadi Al-Jizzi, Figure 2.9. Groundwater levels are presented in Appendix C.

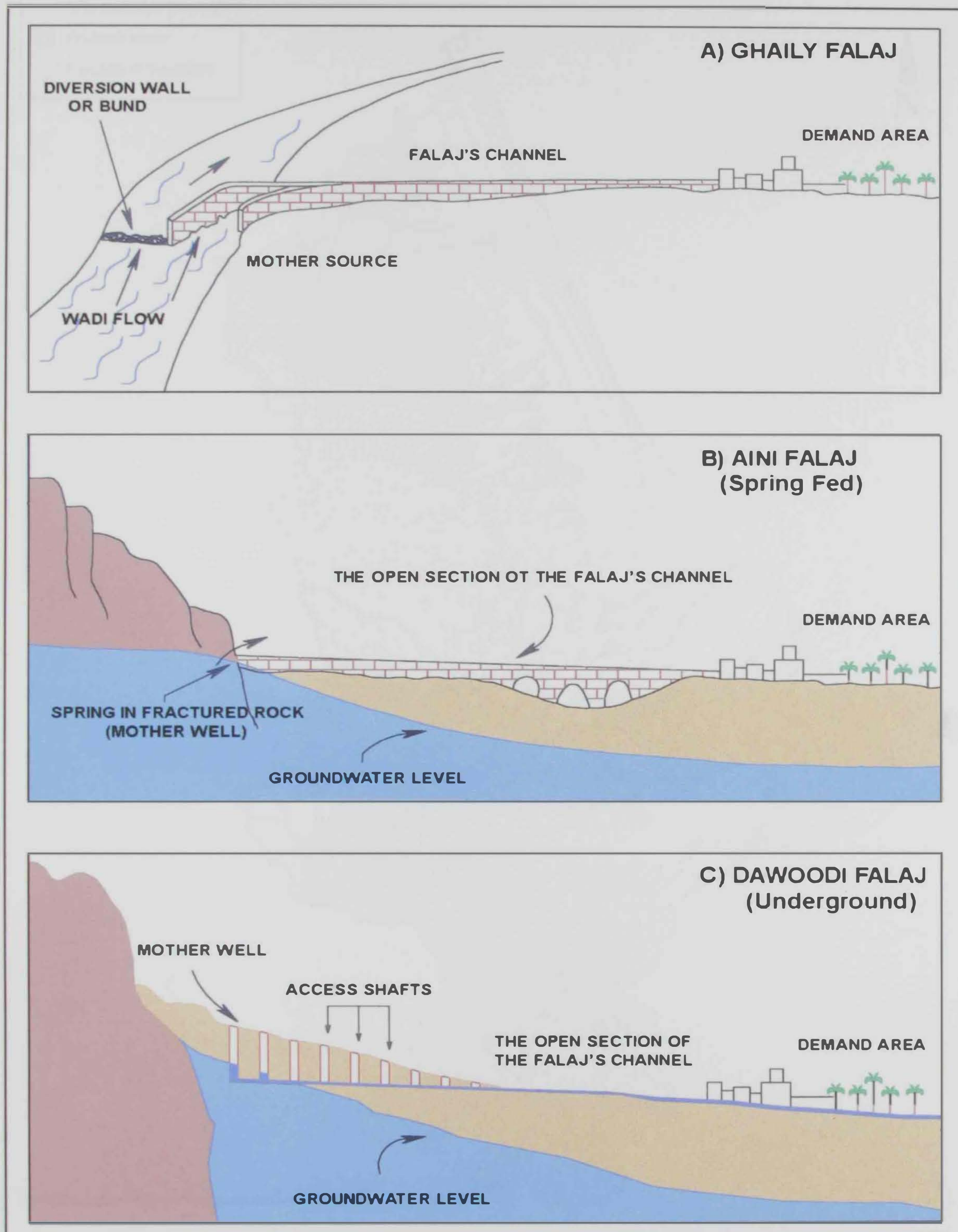


Figure 2.7. Ideal cross-section for types of Aflaj in Oman (GISS, MRMEWR)

Figure 2.8. Shinas-Liwa-Sohar water table contours for the alluvium (Sep 1996) (MWR, 1999b)

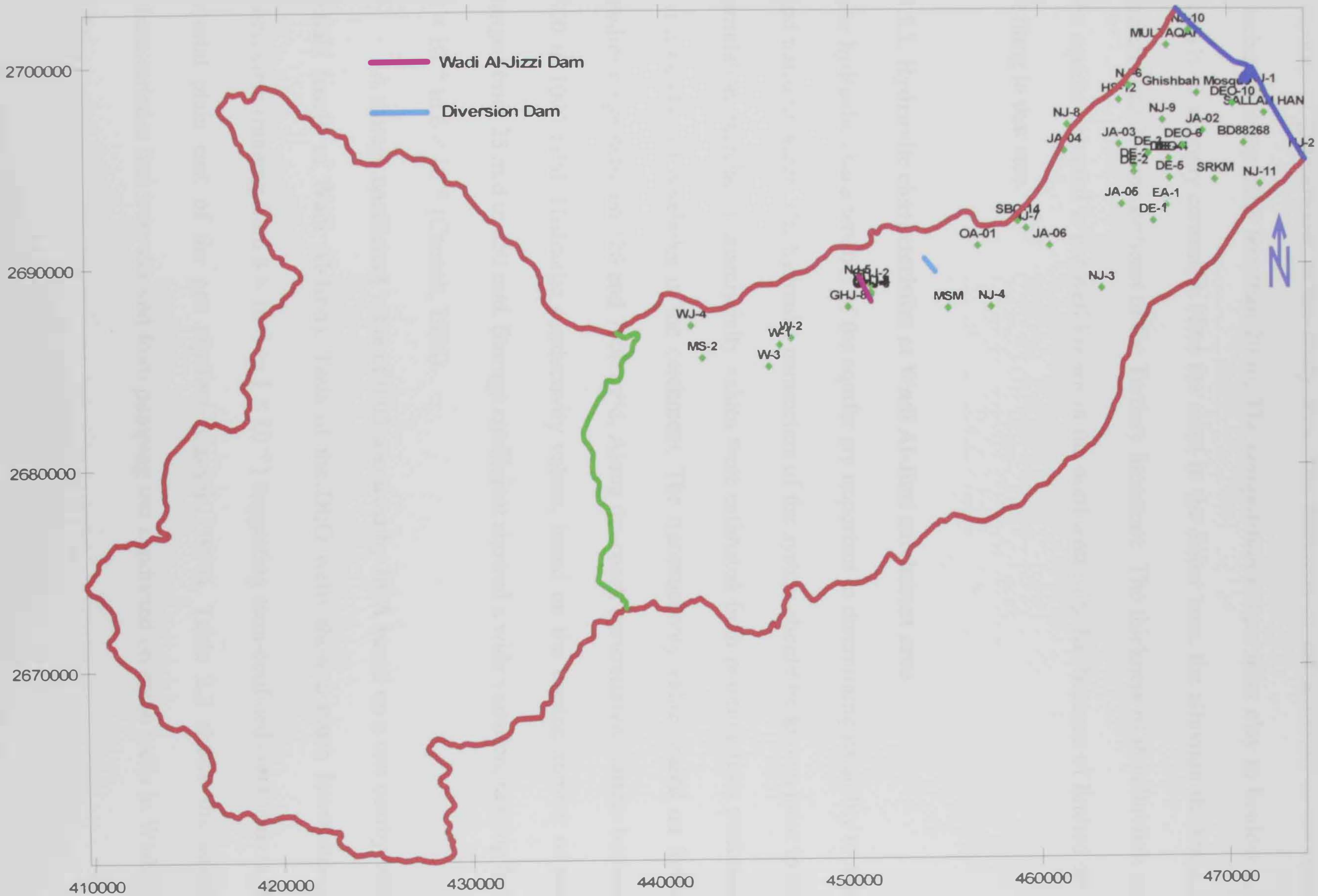


Figure 2.9. The distribution of monitoring wells in Wadi Al-Jizzi catchment

2.5.1. Extent and thickness

The main aquifer within the coastal plain is formed of alluvial deposits that supply the majority of groundwater in the study area. The thickness of the alluvium in the upper catchment is typically less than 20 m. The composition ranges from clay to boulder and weakly to strongly cemented. Near the coast in the Sohar area, the alluvium thickness is greater than 237 m northeast of the Tertiary limestone. The thickness of the alluvium and the aquifer potential is not well known in the northwest of Sohar because of limited deep drilling in that area.

2.5.2. Hydraulic characteristics at Wadi Al-Jizzi catchment area

The hydraulic characteristics of the aquifer are important in determining its ability to store and transmit water. The hydraulic parameters of the system should be known prior to any simulation exercise. Transmissivity values were estimated from pumping tests performed on a number of boreholes in the catchment. The transmissivity values based on former studies range between 126 and 7000 m²/d. Along the coast, transmissivity ranges between 500 to 1000 m²/d. Hydraulic conductivity values, based on the limited number of tests ranged from 25 m/d to 450 m/d. Storage coefficient showed a wide variation, ranging from 1×10^{-4} to 6×10^{-2} (Cansult, 1996).

A storage coefficient value of 0.05 was used by JICA based on a test nearby Wadi Salahi (south of Wadi Al-Jizzi). Tests of the DEO wells show a much lower storage coefficient (ranging from 8×10^{-7} to 1×10^{-5}) suggesting semi-confined conditions in the coastal plain east of the gas pipeline (Cansult, 1996). Table 2.2 shows the aquifer characteristics that were derived from pumping test conducted on some wells in Wadi Al-Jizzi.

Table 2.2. Aquifer characteristics derived from pumping tests (WS Atkins, 2002)

wadi	pumped well	observ. well	coordinates E	coordinates N	radius (m)	24 hr const. rate l/s	drawdown end of test (m)	trans. t - d m²/d	trans. rec m²/d	storage coeff.	source
Jizzi	DE-1		466035	2694530		18.00	2.03	1900	3800		Cansult, 1988
Jizzi		DEO-1			29.34		0.42	4100	4700	$3*10^{-6}$	Cansult, 1988
Jizzi	DE-2		465025	2694844		20.05	3.85	4900	4000		Cansult, 1988
Jizzi		DEO-2			25.25		0.526	3200		$2*10^{-5}$	Cansult, 1988
Jizzi	DE-3		465782	2695456		20.05	3.44	6300	5800		Cansult, 1988
Jizzi		DEO-3			16.85		0.857	5900	5800		Cansult, 1988
Jizzi	DE-4					20.05	1.62	8000	7500		Cansult, 1988
Jizzi		DEO-4	466872	2695192	16.43		0.388	4400		$1*10^{-5}$	Cansult, 1988
Jizzi	DE-5		466905	2694224		20.30	2.28	9700	8000		Cansult, 1988
Jizzi		DEO-5			49.45		0.255	10000		$4*10^{-6}$	Cansult, 1988
Jizzi	N-1		471317	2687707		33.50	15.45	1000?	300?		Bin Hashil, 1977
Jizzi	N-2		471897	2687016		33.80	1.27	10000	11000		Bin Hashil, 1977
Jizzi	79		466488	2692534		31.00	3.56	9800	8700		Khimji Ramdas, 1993

2.5.3. Basal confining system

The thickness of the permeable alluvium varies from about 30 m at the dam site to less than 10 m further downstream crosses the wadi near well NJ-3, Figure 2.9, and significantly increases towards the coastal plain. The depth to bedrock at the coast is known to be more than 240 m in the Sohar-Saham area (IRI, 1978).

Chapter 3. Quantitative and Qualitative Assessment of Groundwater

3.1. Introduction

The headwater (recharging source) of Wadi Al-Jizzi is originated from the easterly-facing slopes of the northern jebal range (Cansult, 1996). The main channel follows a direction to the east towards Sohar town till entering the Gulf of Oman. The channel gets narrower downstream from the dam until it enters the coastal plain where it divides to form overflow channels on both sides. Wadi Al-Jizzi channel is incised in the base of a narrow valley in the eastern part of the upper catchment. The valley widens near Al Wasit to the west. The wadi channels are typically comprised of coarse alluvium. In the west, the recent wadi deposits are flanked and often underlain by older, cemented alluvial terrace deposits.

The wadi exits the mountains at Al Mulaynah and enters the lower part of the catchment on the Batinah plain. Further east, the wadi enters the coastal plain which has gentle to flat slopes. The wadi channels eventually converge near the main highway and cross a 2.5 km wide coastal strip. The wadi channel is 650 m wide at the dam location, Figure 3.1.

The downstream overflow spread through the alluvial fan into channels during high flood conditions. It should be noted, however, that the Wadi Al-Jizzi Dam has reduced the possibility of overflows from Wadi Jizzi main channel.

The Wadi Al-Jizzi total catchment area is about 1154.78 km^2; the upper catchment area is about 635.09 km^2 and the lower catchment area is about 519.69 km^2. Wadi Al Jizzi consists of significant tributaries upstream from the dam site; Wadi Hayl, Wadi Al Thuabah, Wadi Kitnah, Wadi Farfar and Wadi Lasail.

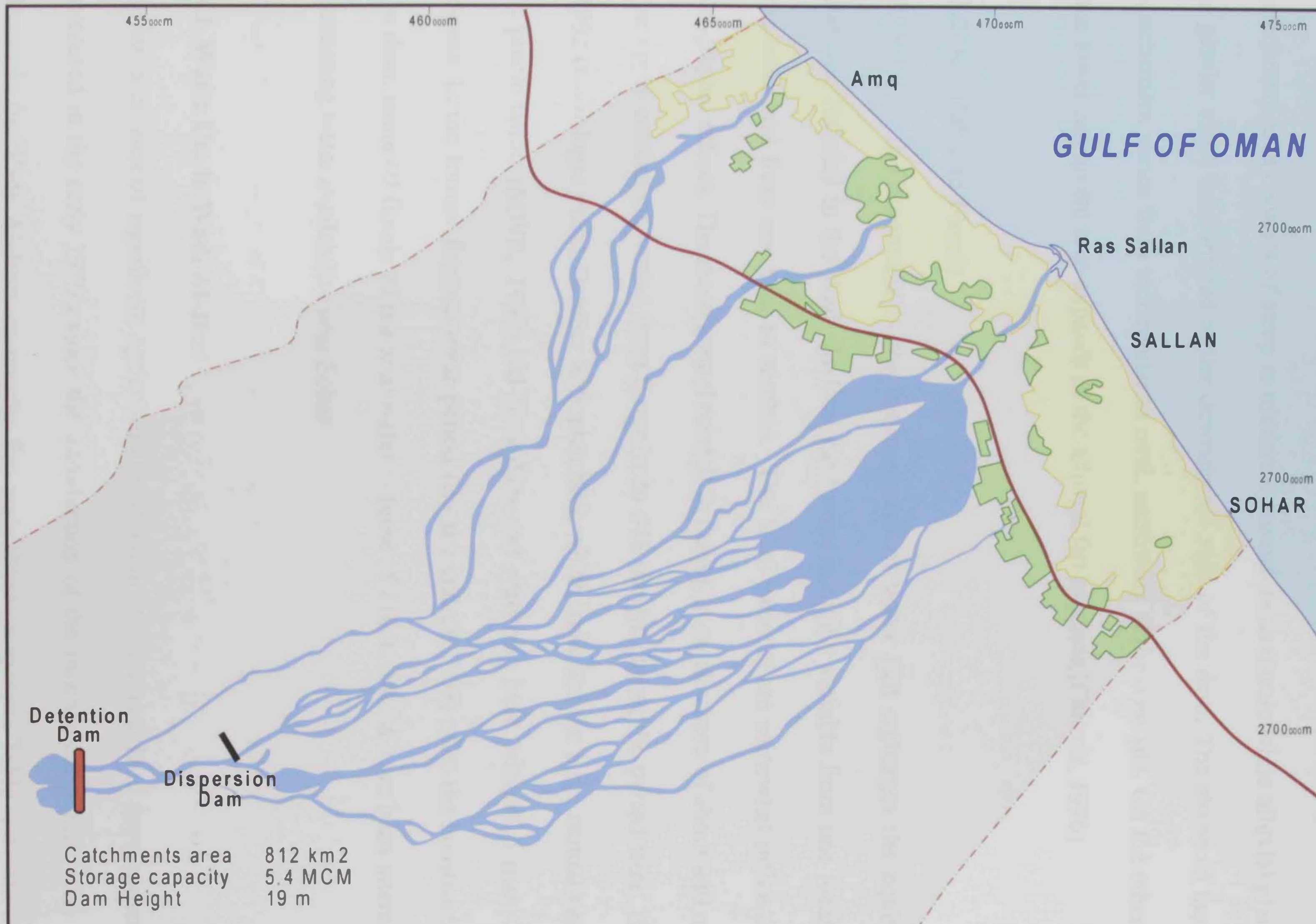


Figure 3.1. Wadi Al-Jizzi channels and overflow streams

The majority of these attributes (with exception of Wadi Lasail) flow entering the reservoir area are all measured by the Wadi Al Jizzi wadi gauge near Mulayinah. Wadi Lasail joins Wadi Al Jizzi at the upper end of the reservoir area. The head of the catchment area consists of steep to moderate mountainous terrain while alluvial plain with a gentler slope encountered at the downstream side of the dam. The shape of the upper catchement varies from rectangular to oval, narrowing at the dam site. On the other hand, the lower catchment area expands as the alluvial fan expands (Cansult, 1996).

3.2. Rainfall and Floods

Rainfall on the mountains is the major source of water that recharges the aquifers in Batinah. Rainfall in the Wadi Al-Jizzi catchment is highly variable from one location to the other and from one year to another. The local patterns are somewhat influenced by orographic effects. The mean annual rainfall in Daqiq, at an elevation of about 840 masl in the upper catchment, varied from 0 mm/yr to 448 mm/yr during the period from 1973 to 1992 (hydrologic years, October to September), which indicates the large annual variation in precipitation (MWR, 1999). Al-Jizzi dam and reservoir have witnessed many flood events. In the former fourteen-year period (till the end of 2003) after the construction of the dam, some 69 floods with a total water volume of 116.44 MCM have been intercepted, increasing water availability near Sohar.

3.3. Water Use in Wadi Al-Jizzi

Sohar is an area of significant agricultural production. Agricultural land development has increased in the early 1970's since the introduction of the mechanical pumps. The water demands in Wadi Al-Jizzi is mostly for agriculture purposes. Table 3.1, shows the different uses of water resources in the catchment. The total consumption of groundwater

Table 3.1. Water demands in Wadi Al-Jizzi catchment (MWR, 1999)

Water Use	Jizzi East (Mm^3/yr)	Jizzi West (Mm^3/yr)	TOTAL (Mm^3/yr)
Agriculture	27.53	0.48	28.01
Domestic and Household	1.03	0.11	1.14
Municipality, Industrial and Commercial	0.0047	0.0206	0.0253
Livestock	0.1239	0.0082	0.1321
TOTAL	28.6886	0.6188	29.3074

in Wadi Al-Jizzi catchment according to the master plan is about 29 MCM/year, compared to an average of 26 MCM/year of recharge directly from rainfall to the aquifer (MWR, 1999b). In the wet period, the recharge may increase and compensate a large amount of the deficit in the previous years. However, the overall shortage increases due to the increasing groundwater abstraction to cover the increase in population and agriculture activities.

In 1988, the discharge rate for Sohar Development Office (SDO) wellfield was 1,470 m^3/day, and the agricultural demand and other uses was 69,860 m^3/day. Total extraction was then about 26 MCM/year. The demand was increasing from the SDO wellfield by an average of about 112,000 m^3/year till year 2001. The annual increase of pumping rate for agriculture purposes was estimated to be 320,000 m^3/year

3.3.1. Sohar Development Office (SDO) wellfield

A significant proportion of drinking water of Sohar city is developed from a well field operated by the Water Department of the SDO. This well field comprises 8 production wells and is located in Wadi Al-Jizzi east about 8 km from the coast on a gravel plain area, south of Sohar city. The approximate location of the well field is shown on Figure 3.2.

The SDO well field was commissioned in 1984 after the construction of two production wells in 1983 (wells 7 and 8). Production wells 11 and 12 were added in 1991 and another two wells were constructed in 1993 (wells 78 and 79). In 1997, wells N1 and N2 were added to complete the present well field. During this period annual production has increased from about 0.5 MCM in 1984 to about 2.5 MCM in 2003.

This well field was susceptible to cause some decline in groundwater levels during drought periods. However, levels were fully recovered since 1995 in response to good rainfall (MWR, 1999).

3.4. Seawater Intrusion

When groundwater is pumped from aquifers that are in direct hydraulic connection with the sea, the hydraulic gradients may induce a flow of saline water from the sea toward wells. The migration of salt water into freshwater aquifers under the influence of groundwater development is known as seawater intrusion (Walton, 1970), Figure 3.3. The seawater intrusion process is also known as saline-water intrusion (Dion and Sumioka, 1983). Seawater intrusion occurs when fresh water is withdrawn faster than it can be recharged near a coastline. Seawater generally intrudes upward and landward into aquifer and around a well, though it can occur "passively" with any general lowering of the water table near a coastline. The transition zone where freshwater naturally mixes with seawater as it is discharged to the sea, naturally descends landward as a wedge within aquifers along the coastline. It is this somewhat mobile transition zone which wells tap into when seawater intrusion is usually first noticed (MWR, 1992).

The occurrence of saltwater intrusion is identified by increasing concentrations of sodium and chloride and by elevated specific conductivity and dissolved solids. Typically, the concentration of chloride ions in water is used to identify saltwater intrusion.

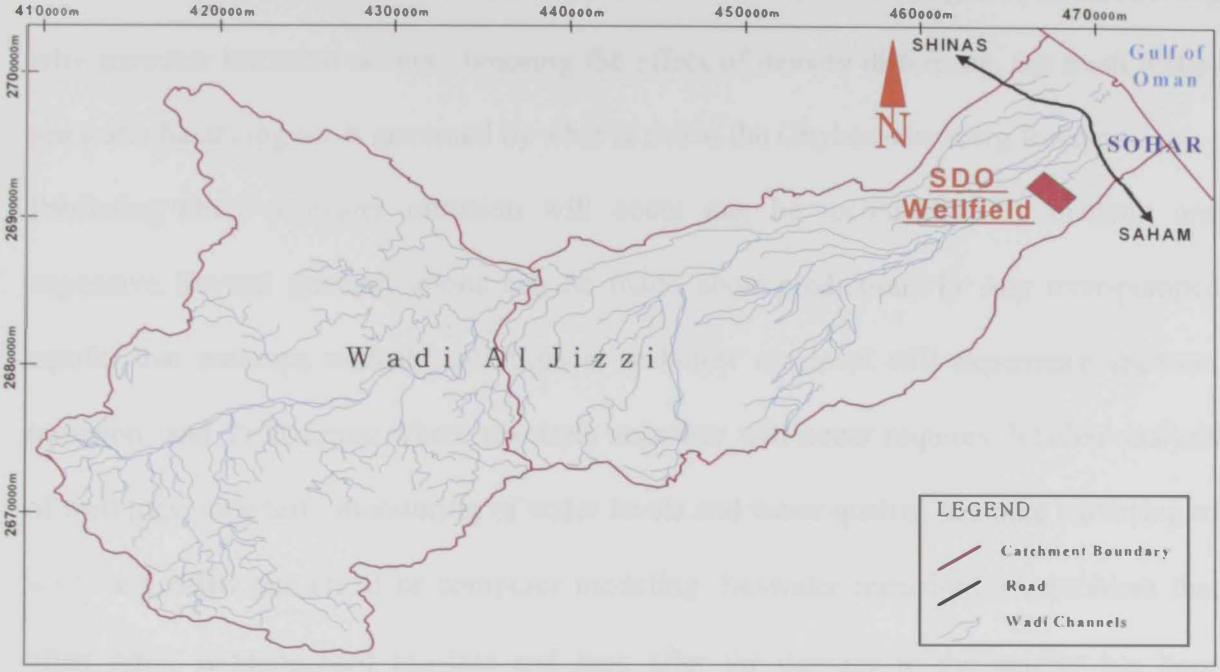


Figure 3.2. Sohar city well field location map

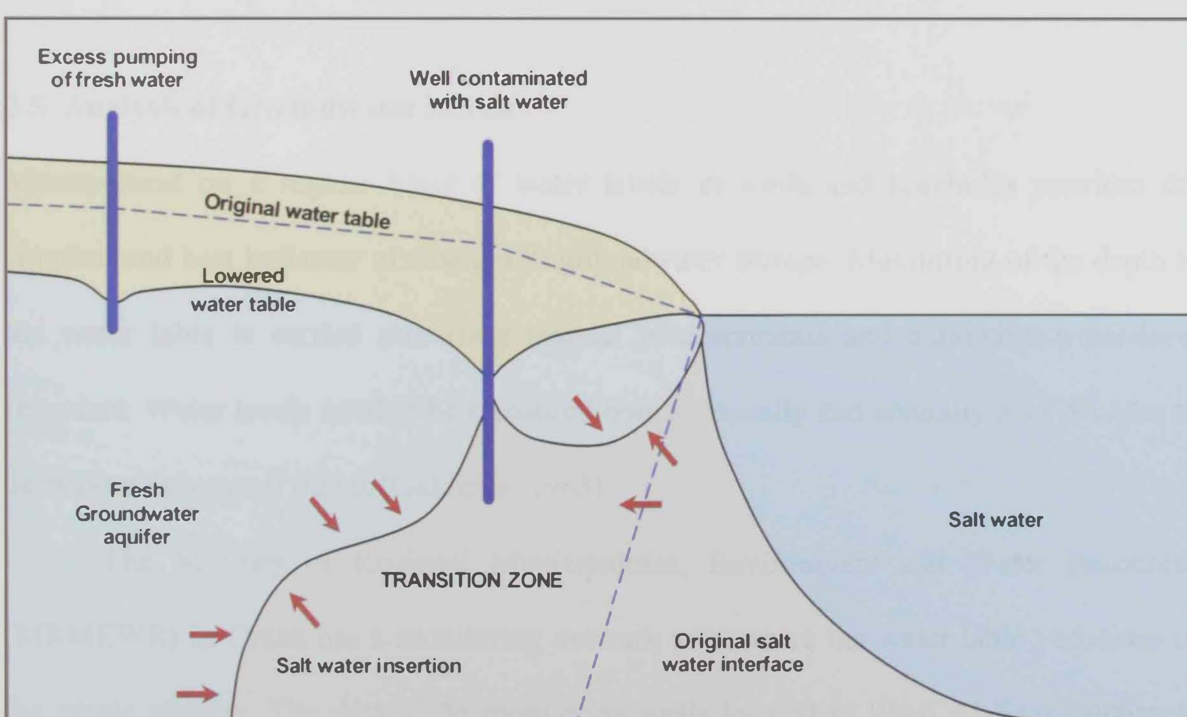


Figure 3.3. Salt water intrusion in the coastal areas

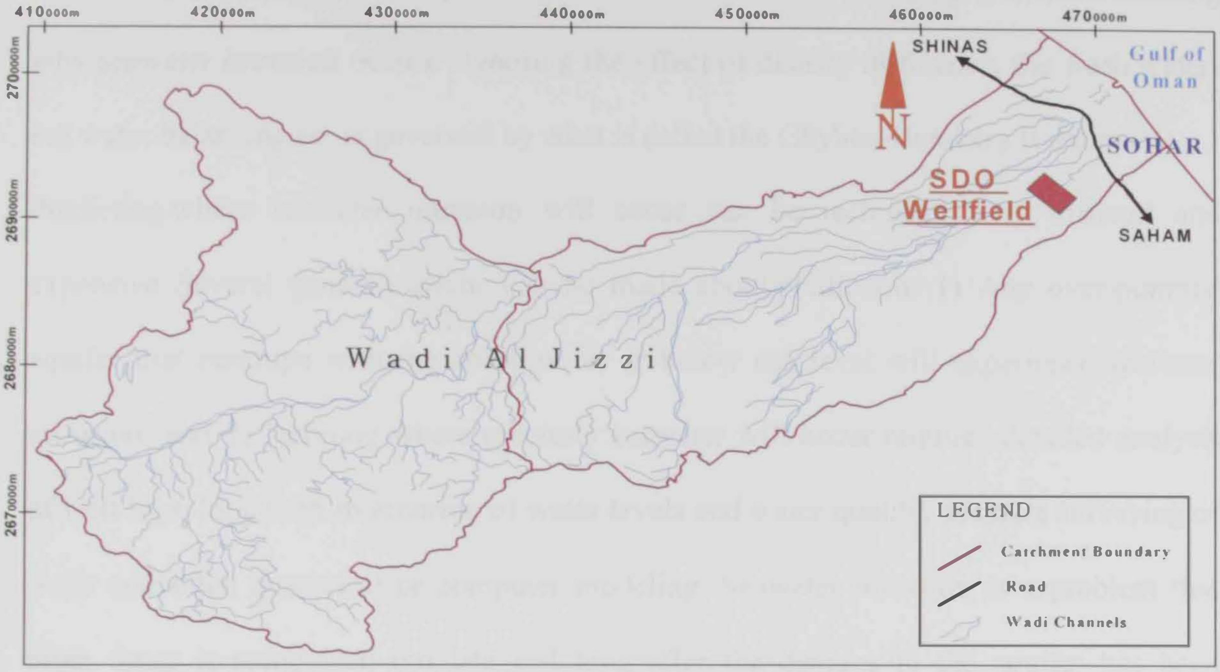


Figure 3.2. Sohar city well field location map

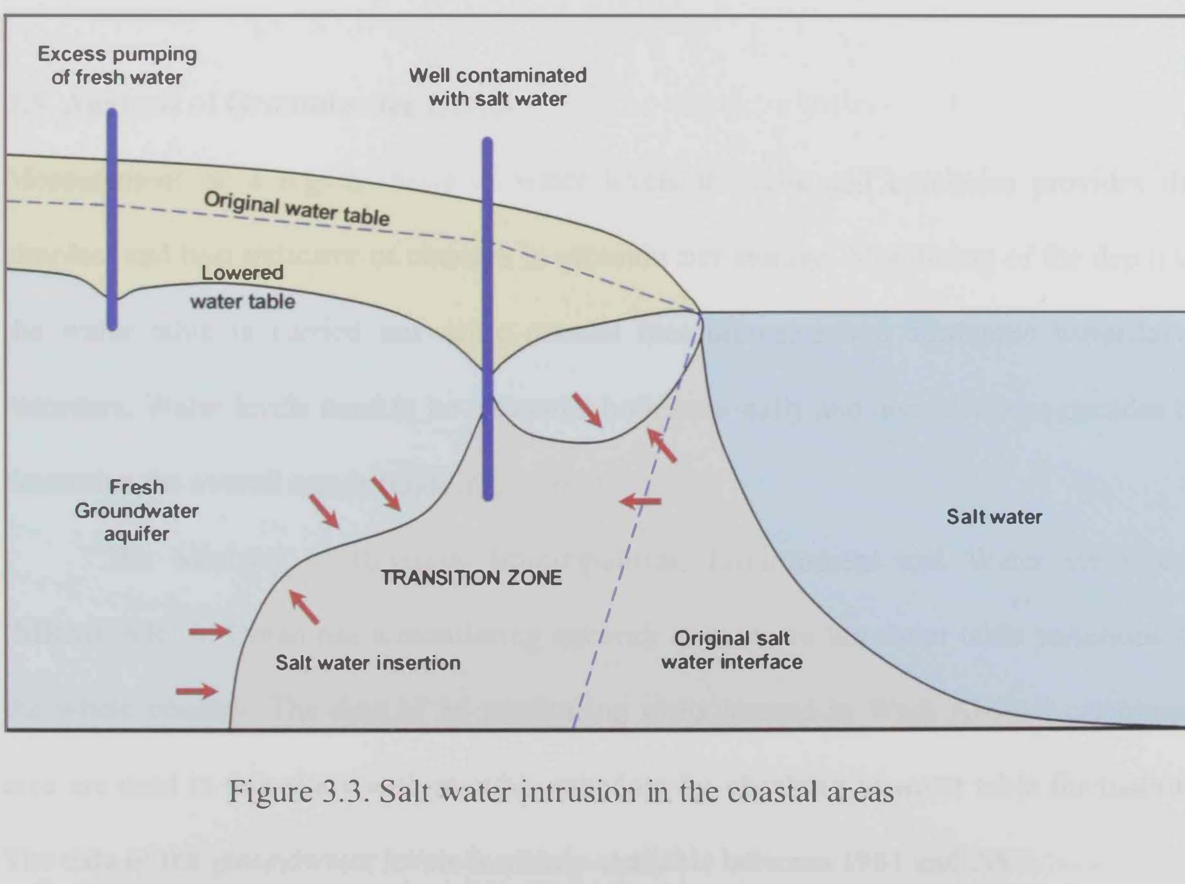


Figure 3.3. Salt water intrusion in the coastal areas

The density difference between the fresh and seawaters causes the fresh water to float above the transition zone at and below seawater level and is integral to understanding why seawater intrusion occurs. Ignoring the effect of density difference, the fresh water-sea water balancing act is governed by what is called the Ghyben-Herzberg Relation. Predicting where seawater intrusion will occur can be technically very difficult and expensive. Several generalizations can be made about prediction: 1) Any over-pumped aquifer that outcrops with the coastline at or below sea level will experience seawater intrusion; and 2) Defining where precisely seawater will occur requires detailed analysis of well logs, long term monitoring of water levels and water quality, accurate surveying of wells and often numerical or computer modeling. Seawater intrusion is a problem that often times is recognized too late and long after the damage to the aquifer has been done. The most obvious remedy is to step down or reduce the rate of pumping from wells or aquifer. Conservation measures can be performed before a problem arises.

3.5. Analysis of Groundwater Levels

Measurement on a regular basis of water levels in wells and boreholes provides the simplest and best indicator of changes in groundwater storage. Monitoring of the depth to the water table is carried out using manual measurements and automatic water-level recorders. Water levels need to be measured both seasonally and annually over decades to determine the overall trends (Giddings, 1983).

The Ministry of Regional Municipalities, Environment and Water Resources (MRMEWR) in Oman has a monitoring network to measure the water table variations in the whole country. The data of 36 monitoring wells located in Wadi Al-Jizzi catchment area are used in this study with monthly schedule for checking of water table fluctuation. The data of the groundwater levels is mainly available between 1981 and 2003.

The increase in amount of groundwater withdrawal in the Batinah coastal plain with lower recharge rates has caused a significant disturbance in the groundwater balance. As a result, groundwater levels declined below mean sea level, especially in coastal areas.

3.5.1. Before the construction of Wadi Al-Jizzi dam

Previous studies, including JICA (1985), indicated that the groundwater contour lines close to the sea were almost parallel to the coast line, Figure 3.4. Near the coast line of Wadi Al-Jizzi the groundwater level was more than 1 meter above mean sea level. This situation was observed between Apr. 1974 and May 1985. Figure 3.5 shows a contour map for the highest groundwater level period for the year 1978. According to the available data, the high groundwater levels were observed in 1977 and 1978 while the low groundwater levels were observed in 1983 and 1985.

3.5.2. After the construction of Wadi Al-Jizzi dam

The Wadi Al-Jizzi unconfined aquifer is characterized by shallow water table within 20 meters below the ground surface in the coastal area. Water level fluctuations in the coastal area of the catchment are dominated by pumping and small seasonal recoveries and appear to be buffered by high storage and the compensatory movement of the seawater interface. Due to the excessive pumping, water levels in some coastal wells are now below sea level. The monitoring wells in the coastal areas typically display relatively small amplitude fluctuations. The response is remarkably consistent throughout the zone, indicating that hydrogeological conditions near the coast are relatively uniform.

Figure 3.6 shows the hydrograph of the monitoring well JA-03, which is located within the agricultural area strip west of the main road, 15 km downstream of the dam. It indicates the changes in water levels during the period from January 1985 to June 2003.

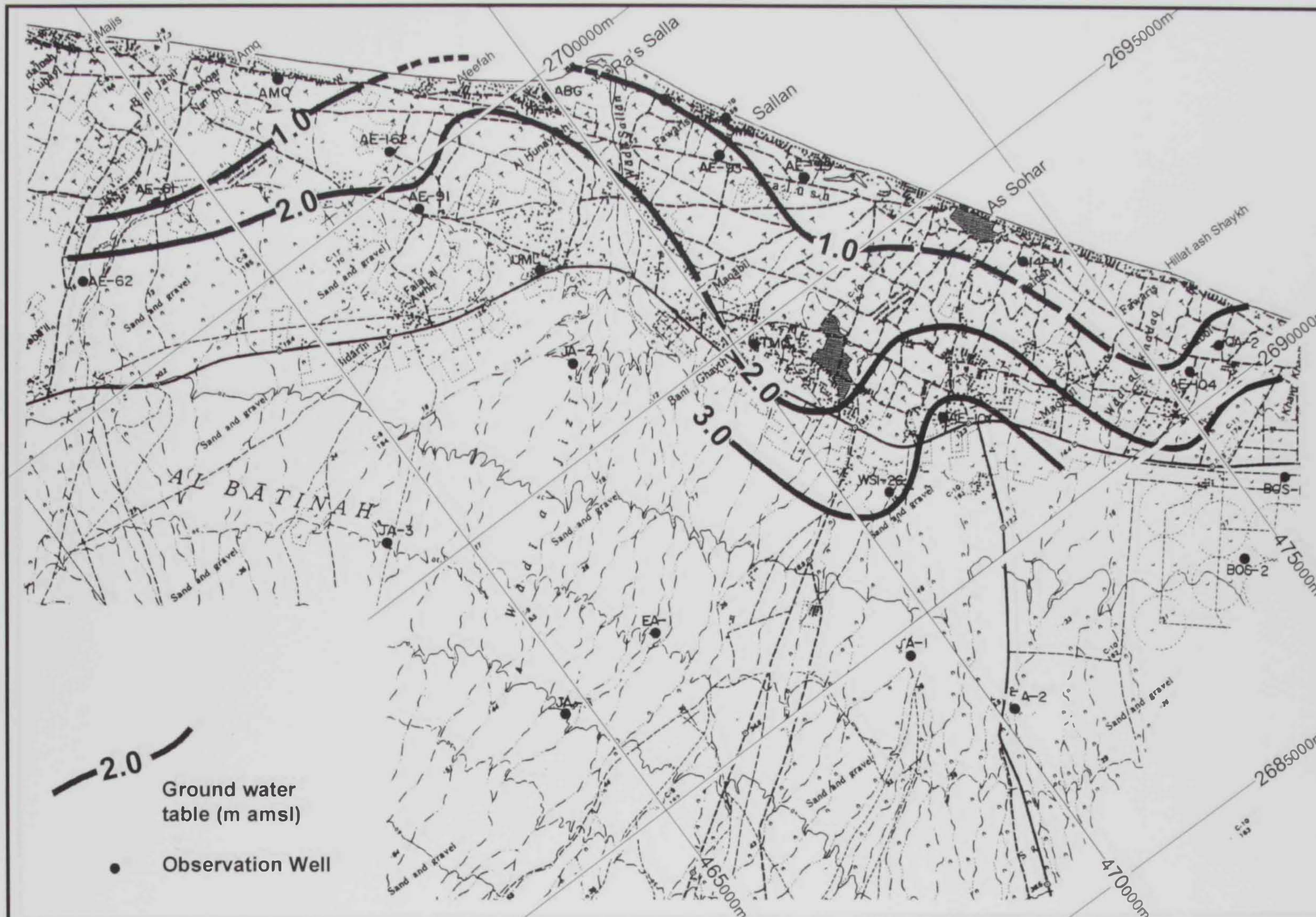


Figure 3.4. Mean groundwater table between Apr. 1974 and May 1985 (JICA, 1985)

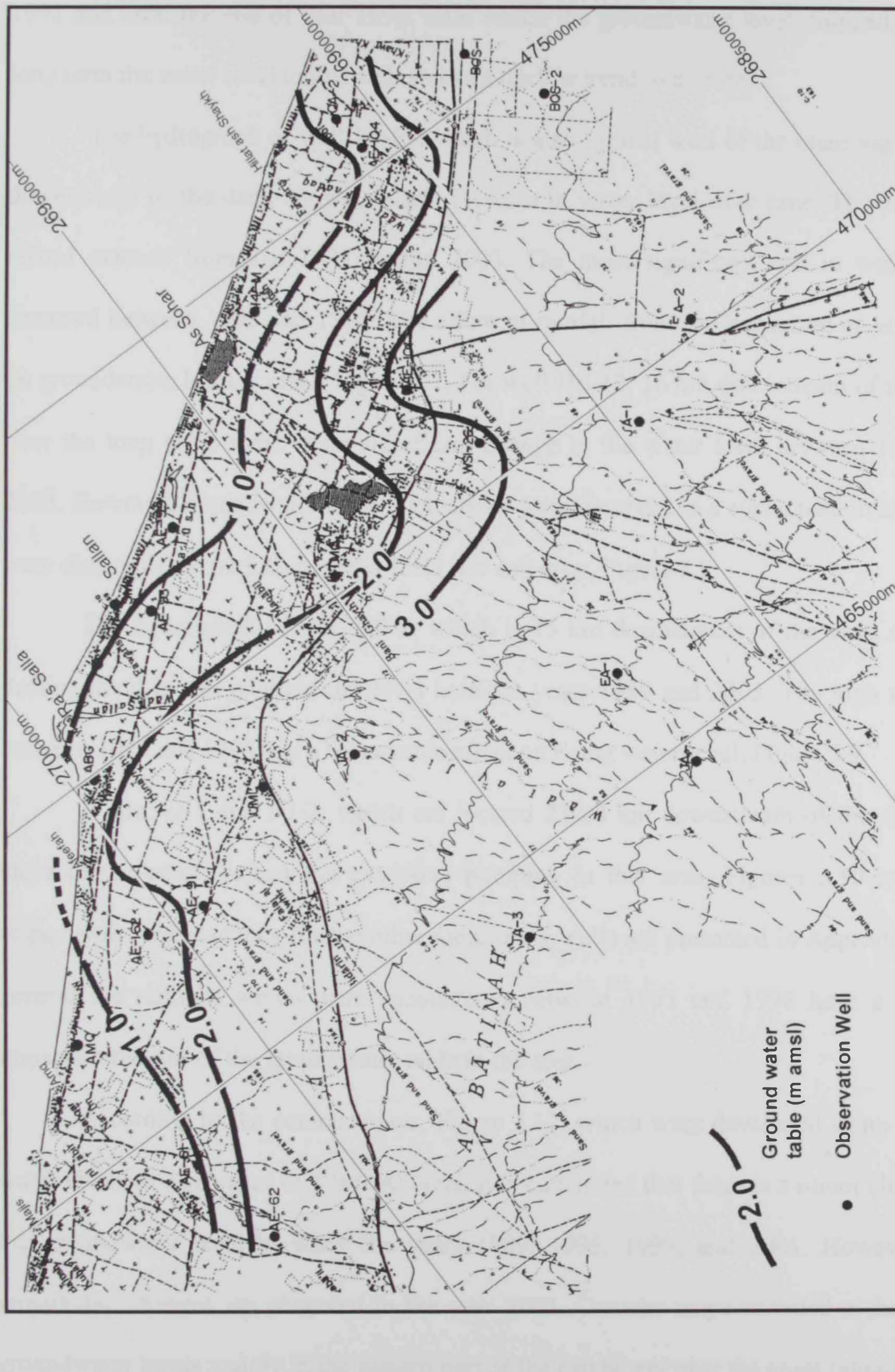


Figure 3.5. Groundwater table in 1978 (JICA, 1985)

There was a rise in the water level from the beginning of year 1985 until mid 1987. The water level declined again after 1987. The second rise was observed between year 1992 and until the end of year 1996, after which the groundwater level dropped. On the long term the water level in this well shows a decline trend over time.

The hydrograph of well JA-05, which is also located west of the main road 14 km downstream of the dam, shows a slight increase in water level over time. The period of record extends from Jan 1985 to Jun 2003. The most significant rise in water level occurred between 1995 and 1998. The effect of rainfall from the beginning of year 1995 on groundwater level is clear, Figure 3.7. For well HS-12, 16 km downstream of the dam, over the long term, there is no significant change in the water level between 1986 and 2003. However, groundwater level fluctuations were observed in a cyclic pattern and there were distinguished periods of water level rise and drop, Figure 3.8.

The hydrograph of well DE-2, which is 15 km downstream of the dam, shows a decline trend in the groundwater level between years 1989 and 2003. The high rainfalls between 1995 and 1998 had a remarkable effect on rising water level, Figure 3.9.

Wells NJ-1 and NJ-2, which are located 23-24 km downstream of the dam and close to the coast, reflect the excessive pumping in that area, Figures 3.10 and 3.11 respectively. Hydrographs for the other monitoring wells are presented in Appendix D. In general the rainfalls which were encountered between 1995 and 1998 have a notable impact on the rise of the groundwater table in the area.

According to the contour maps, Figure 3.12, which were developed using ground water levels in catchment of Wadi Al-Jizzi, it is concluded that there is a minor change in the groundwater level between the years 1989, 1995, 1999, and 2001. However, the remarkable changes are observed in the year 2003. Contour maps revealed a change in groundwater levels mainly in the eastern part of the catchment near the coast (almost 7 km

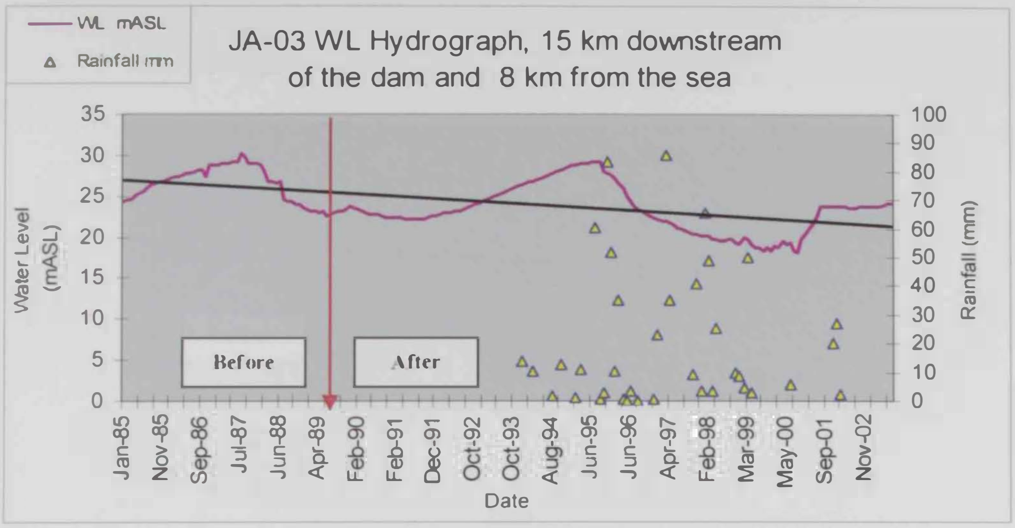


Figure 3.6. JA-03 groundwater monitoring well hydrograph

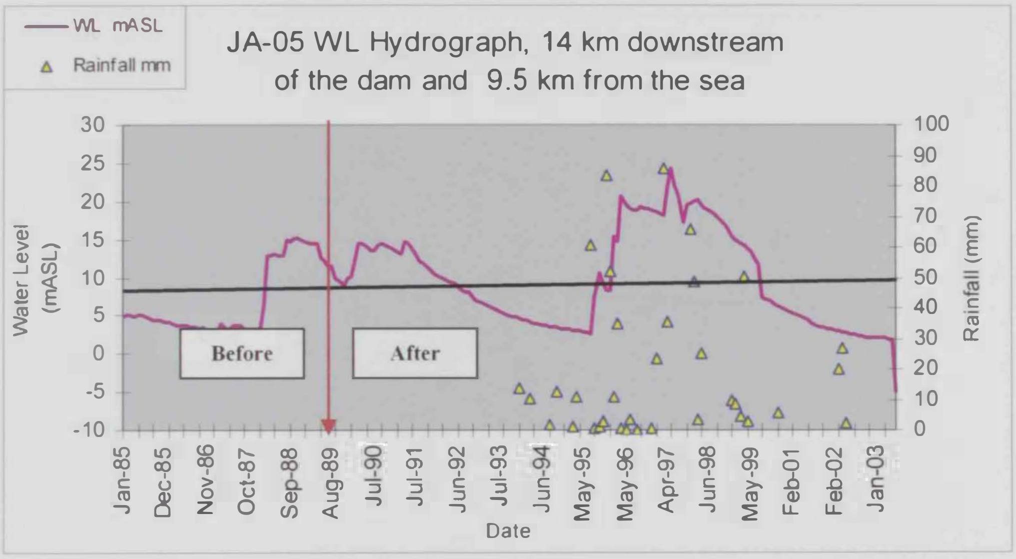


Figure 3.7. JA-05 groundwater monitoring well hydrograph

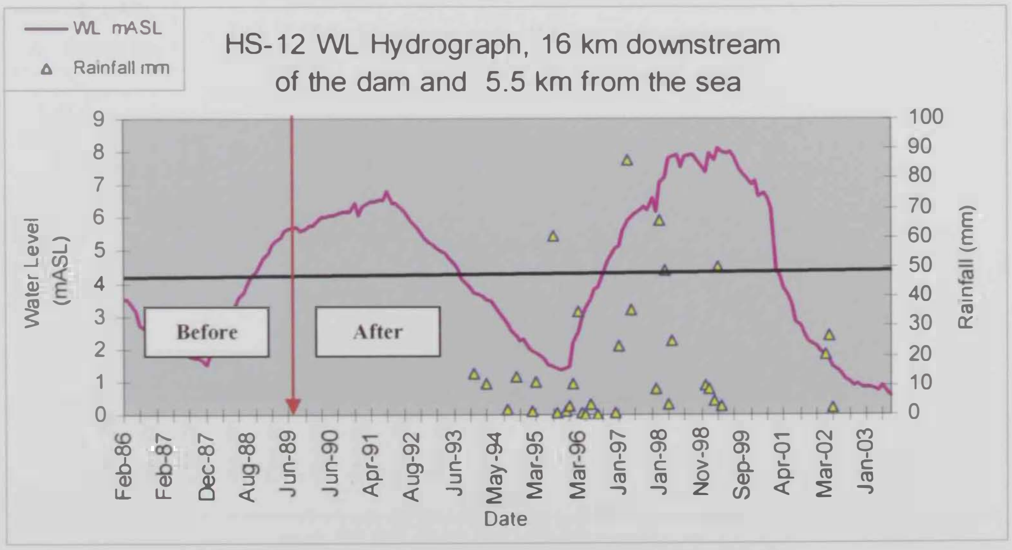


Figure 3.8. HS-12 groundwater monitoring well hydrograph

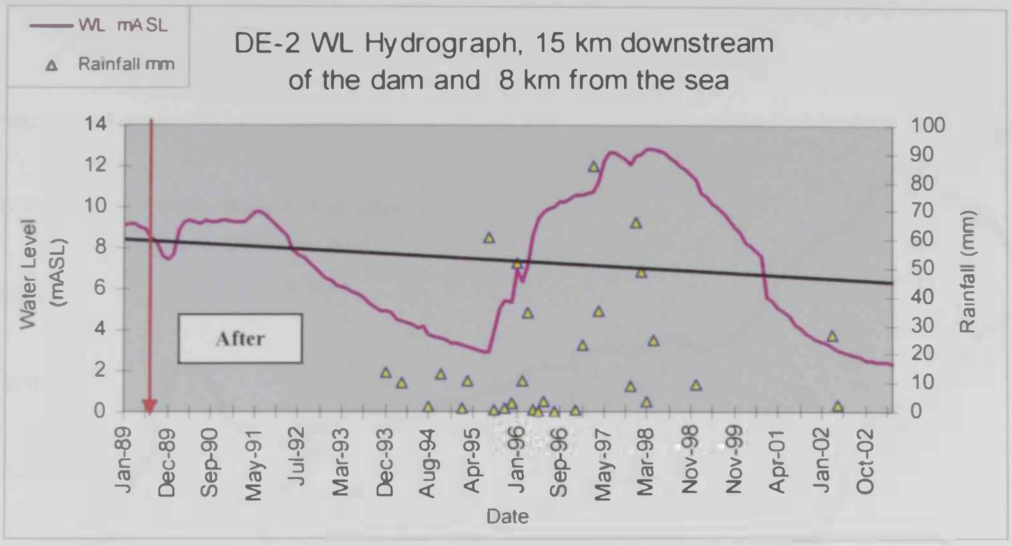


Figure 3.9. DE-2 groundwater monitoring well hydrograph

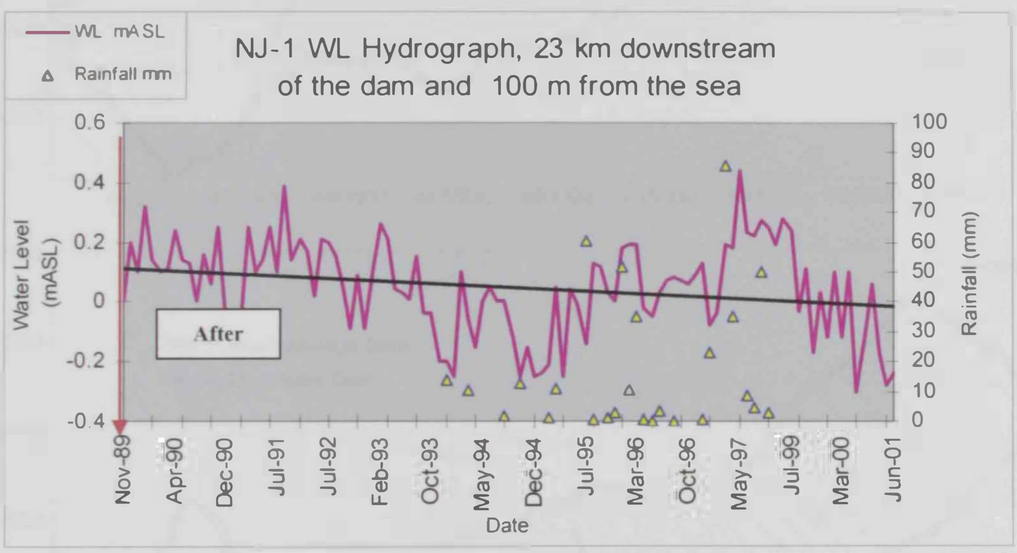


Figure 3.10. NJ-1 groundwater monitoring well hydrograph

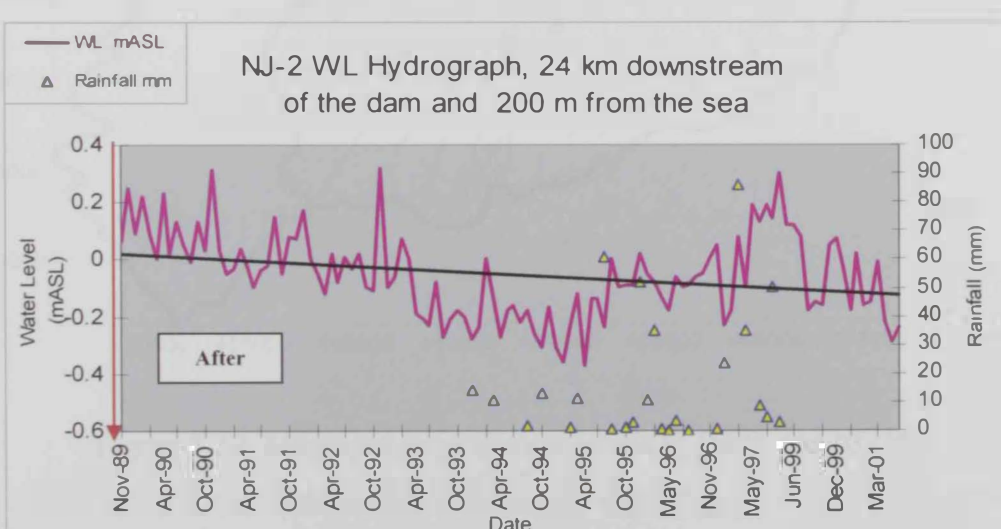


Figure 3.11. NJ-2 groundwater monitoring well hydrograph

Figure 3.12. Measured groundwater levels a) 1989, and b) 1995

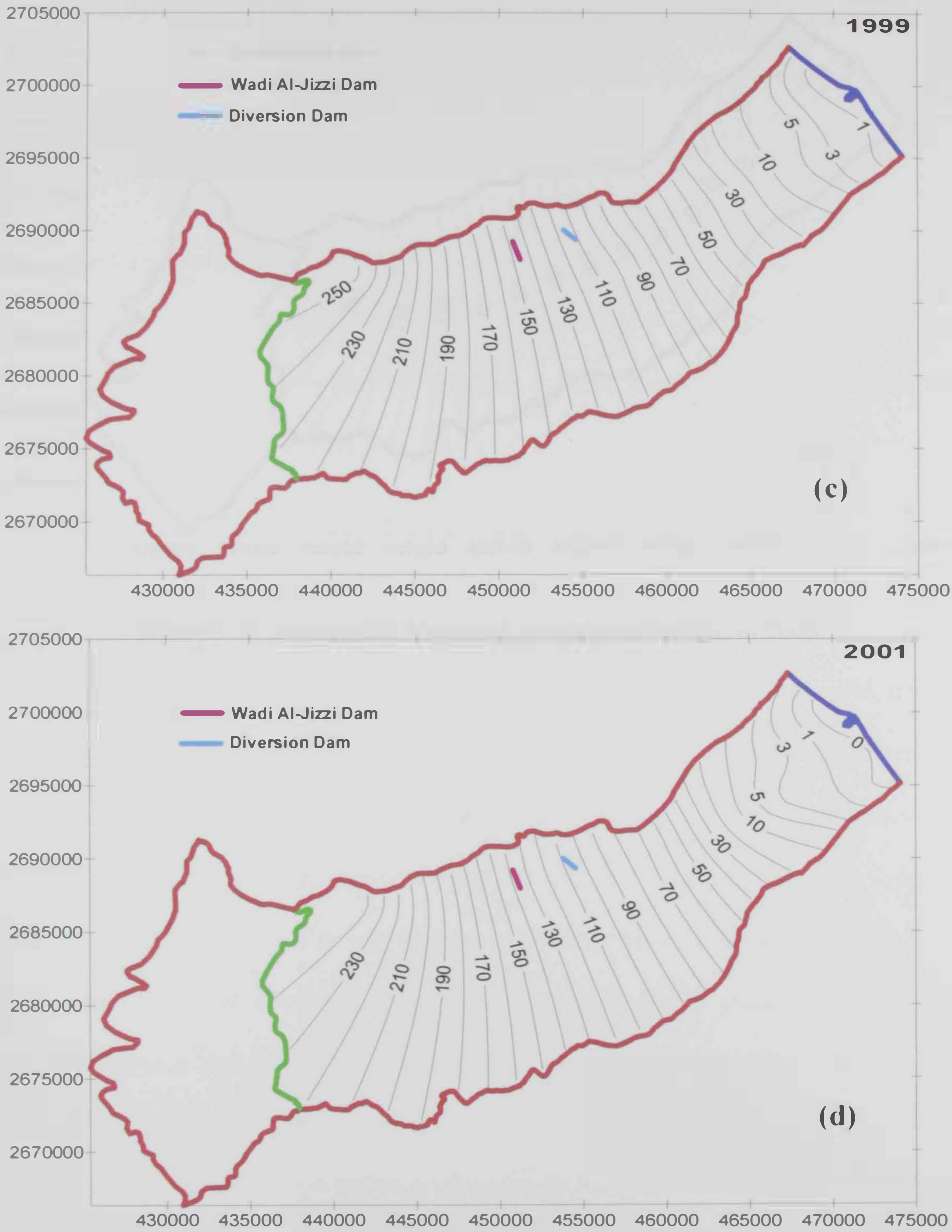


Figure 3.12 (continued). Measured groundwater levels c) 1999, and d) 2001

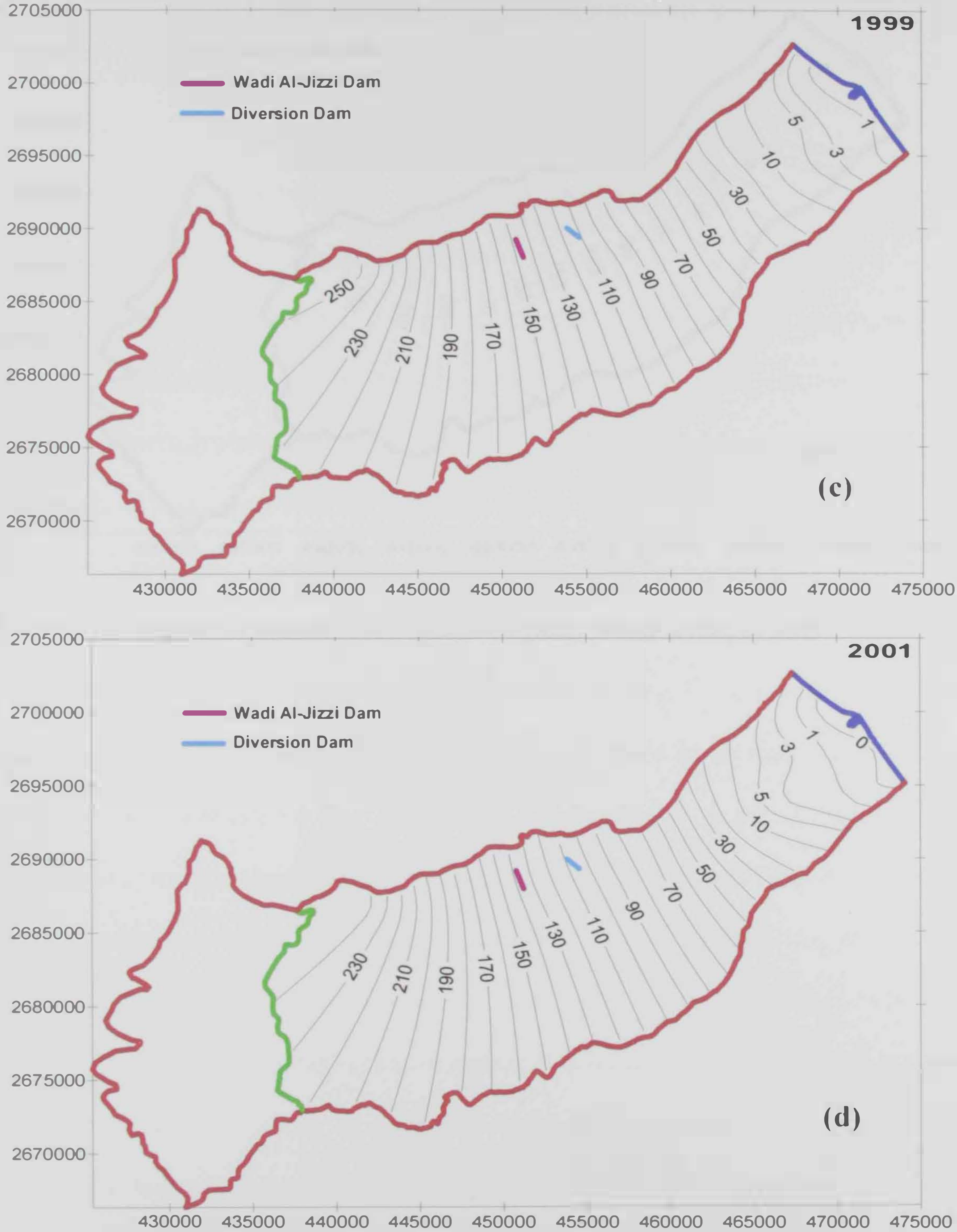


Figure 3.12 (continued). Measured groundwater levels c) 1999, and d) 2001

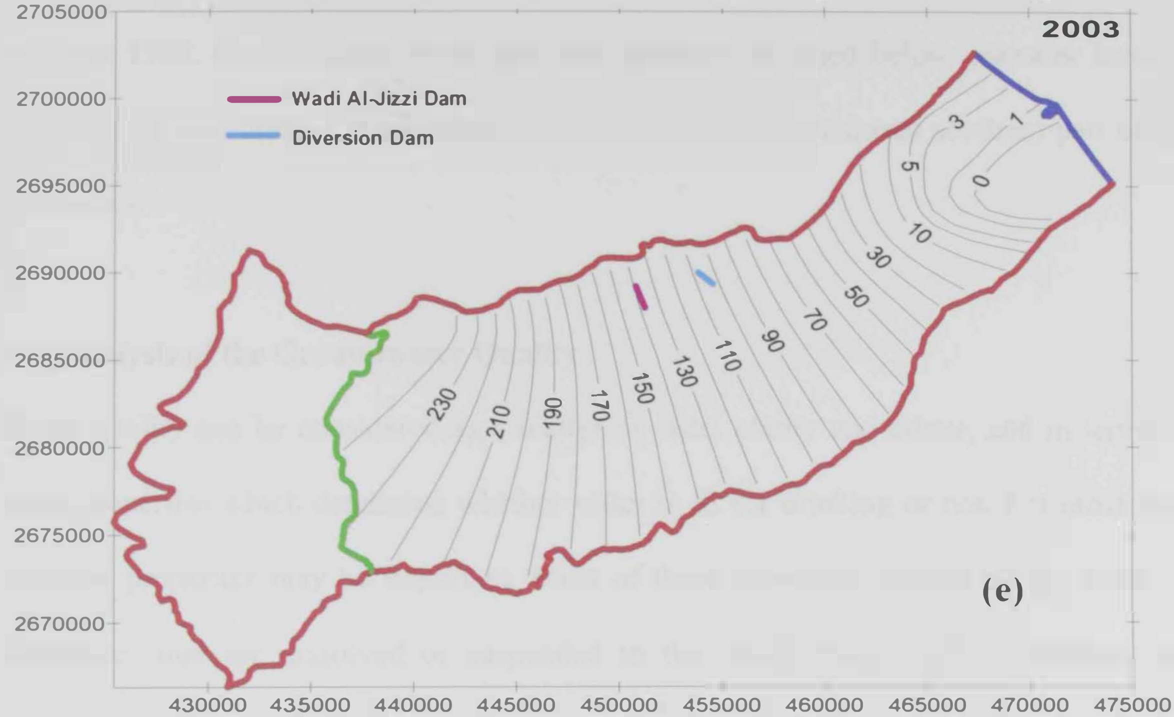


Figure 3.12 (continued). Measured groundwater levels. e) 2003

inland from the sea boundary). Groundwater levels in year 1989 were generally higher than that of the year 1995. This is mainly attributed to the high rainfall in the beginning of the year 1988. Groundwater levels near the shoreline declined below seawater level in 1999. In the year 2003, the shoreline moved inland to cover the east southern part of the catchment.

3.6. Analysis of the Groundwater Quality

Water quality can be considered as a matter of taste, clarity and odour, and in terms of other properties which determine whether water is fit for drinking or not. For other uses different properties may be important. Most of these properties depend on the kinds of substances that are dissolved or suspended in the water. Pure water is tasteless and odorless. Groundwater may contain many constituents, including microorganisms, gases, inorganic and organic materials.

The chemical nature of water continually evolves as it moves through the hydrologic cycle. The kinds of chemical constituents found in groundwater depend, in part, on the chemistry of the precipitation and recharge water. Near coastlines, precipitation contains higher concentrations of sodium chloride, and downwind of industrial areas, airborne sulphur and nitrogen compounds make precipitation acidic.

One of the most important natural changes in groundwater chemistry occurs in the soil. Soils contain high concentrations of carbon dioxide which dissolves in groundwater, creating a weak acid capable of dissolving many silicate minerals. In its passage from recharge to discharge area, groundwater may dissolve substances it encounters or it may deposit some of its constituents along the way. The eventual quality of the groundwater depends on temperature and pressure conditions, on the kinds of rock and soil formations through which the groundwater flows, and possibly on the residence time. In general, faster flowing water dissolves less material. Groundwater, of course, carries with it any soluble contaminants which it encounters (Biswas, 1997).

The suitability of water for a given use depends on many factors such as hardness, salinity and PH. Acceptable values for each of these parameters for any given use depend on the use, not on the source of the water.

As groundwater flows through an aquifer it is naturally filtered. This filtering, combined with the long residence time underground, means that groundwater is usually free from disease-causing microorganisms. A source of contamination close to a well, however, can defeat these natural safeguards. Natural filtering also means that groundwater usually contains less suspended material and undissolved.

Water quality assessment includes the use of monitoring wells to collect groundwater samples and define the condition of the water. This process defines the basis for detecting trends and provides the information needed for the establishment of cause-effect relationships (Chapman, 1996). The overall goal of a groundwater quality assessment programme, as for surface water programmes, is to obtain a comprehensive picture of the spatial distribution of groundwater quality and of the changes in time that occure, either naturarly, or under the influence of man (Wilkinson and Edworthy, 1981).

Salinity in water is normally measured and expressed in terms of electrical conductivity (EC) and total dissolved solids (TDS). Electrical Conductivity (EC) is the ability of a substance to conduct an electrical current. The TDS can be measured rapidly from EC and therefore the salt content in the water.

The concentration of TDS in water is determined by weighing the solid residue obtained by evaporating a measured volume of filtered water. In this study, electrical conductivity (EC) is expressed in units of microSiemen per centimeter ($\mu S/cm$), while total dissolved solids is expressed in milligram per liter (mg/l).

The groundwater in the Batinah Coastal aquifer is already deteriorated. The salt content has increased and the groundwater is not suitable for human consumption according to the Omani drinking water standard (MOCI, 1978). The crops are gradually becoming less productive with the increase of salinity over time.

3.6.1. Before the construction of Wadi Al-Jizzi dam

The JICA study which was conducted in 1985 was focused on the groundwater quality in Wadi Al-Jizzi cachment area. As shown in Figure 3.13, the equiconcentration contour lines were parallel to the coast. The EC values ranged from 3000 to 5000 micro mho/cm, approaching 500 micro mho/cm inland in Wadi Al-Jizzi in the year 1985. The groundwater salinity ranged between 1950 and 3250 mg/l.

3.6.2 After the construction of Wadi Al-Jizzi dam

Salinity is one of the most important issues in Al-Batinah coastal plain. This problem became more severe in the late 80's due to the increase in groundwater pumping. The increase of salinity as total dissolved solids (TDS) is noticed during the years from 1994 to 2003 in Wadi Al-Jizzi lower catchment area, where salinity ranged from 500 to 3200 mg/l. The salinity distribution, shown on Figure 3.14, is quite informative. The contour maps plotted based on the available data between years 1994 and 2003 indicated that a saline intrusion component is present in areas where the TDS of groundwater is greater than 3000 mg/l and moving inland with time.

The equiconcentration contour line of 1500 in 1994 was located at about 1.6 km from the coast. It moved inland to about 3.3 km in 2003. The equiconcentration contour line of 2400 was located near the coast in 1999. In 2003 the salinity in the same area has

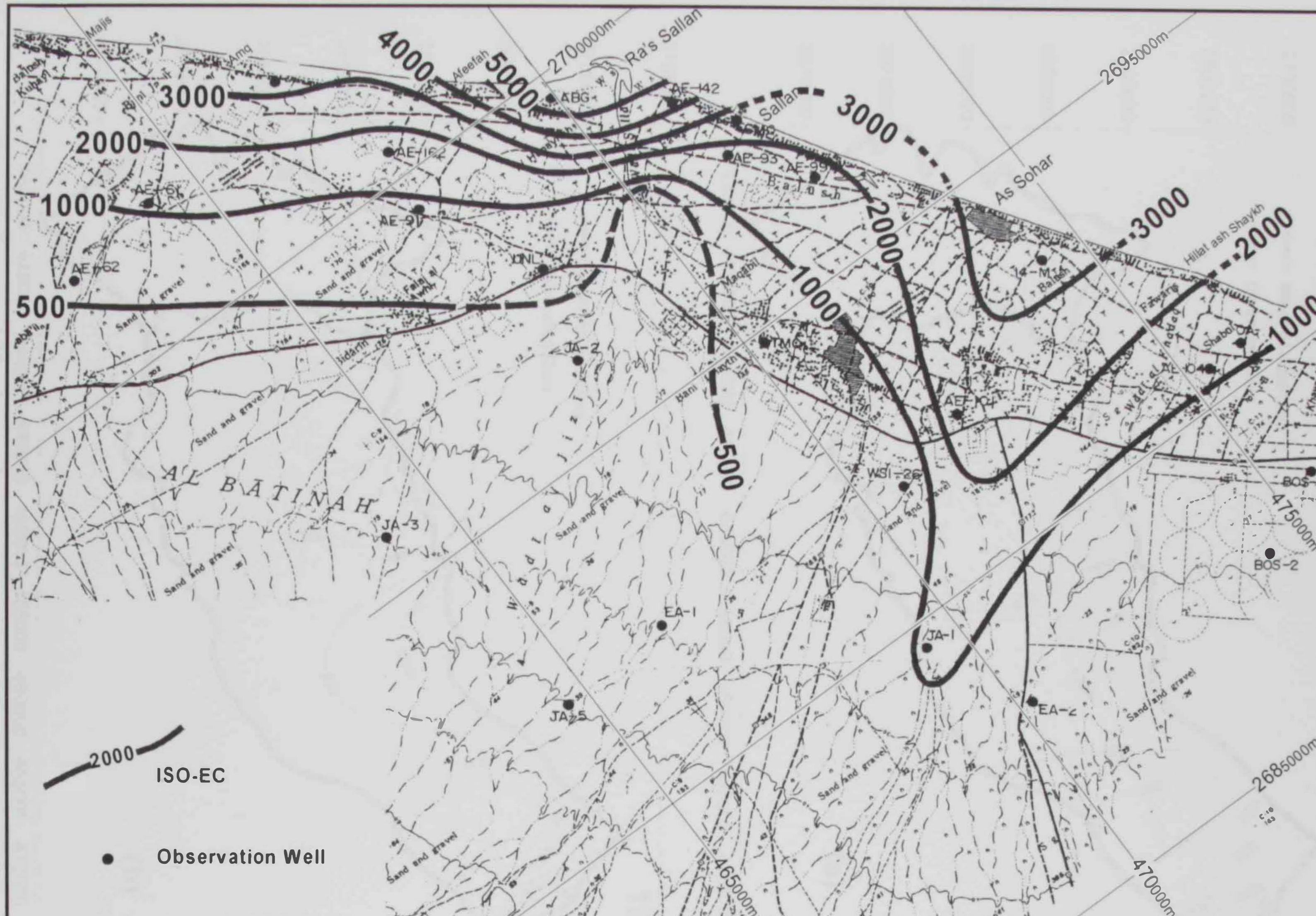


Figure 3.13. ISO – EC map on 1985 (JICA, 1985)

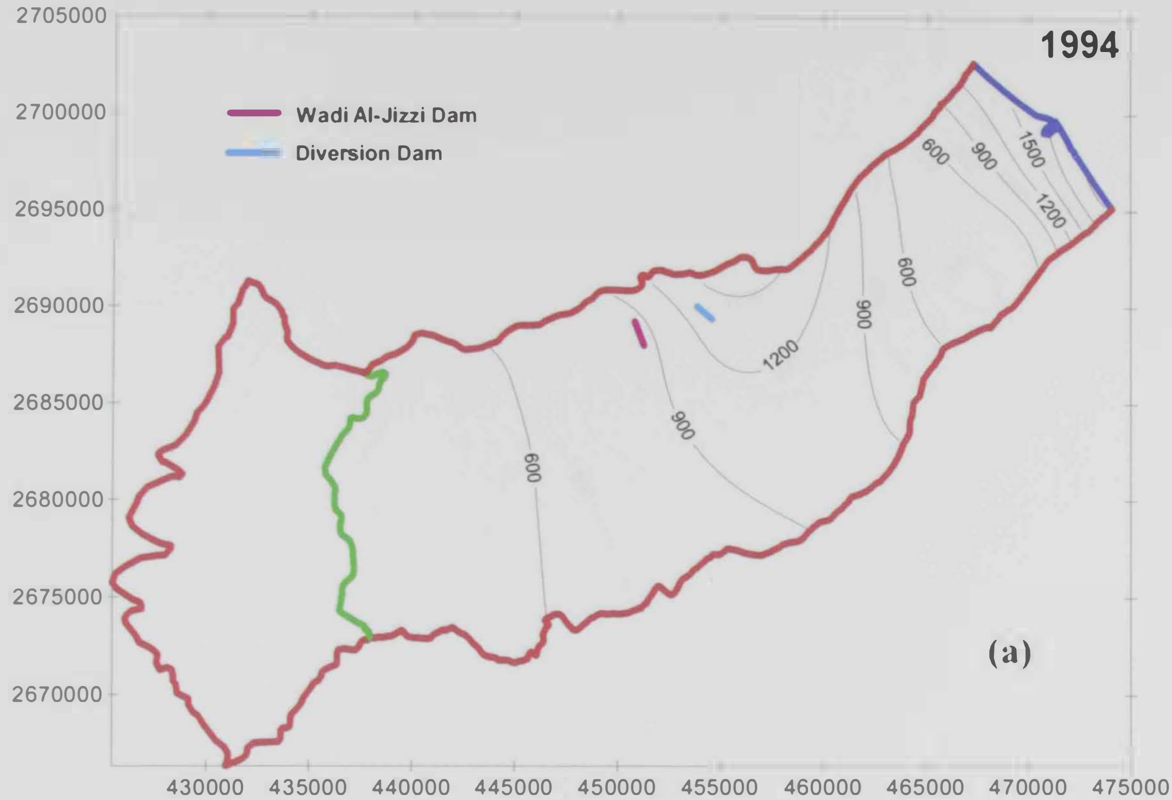
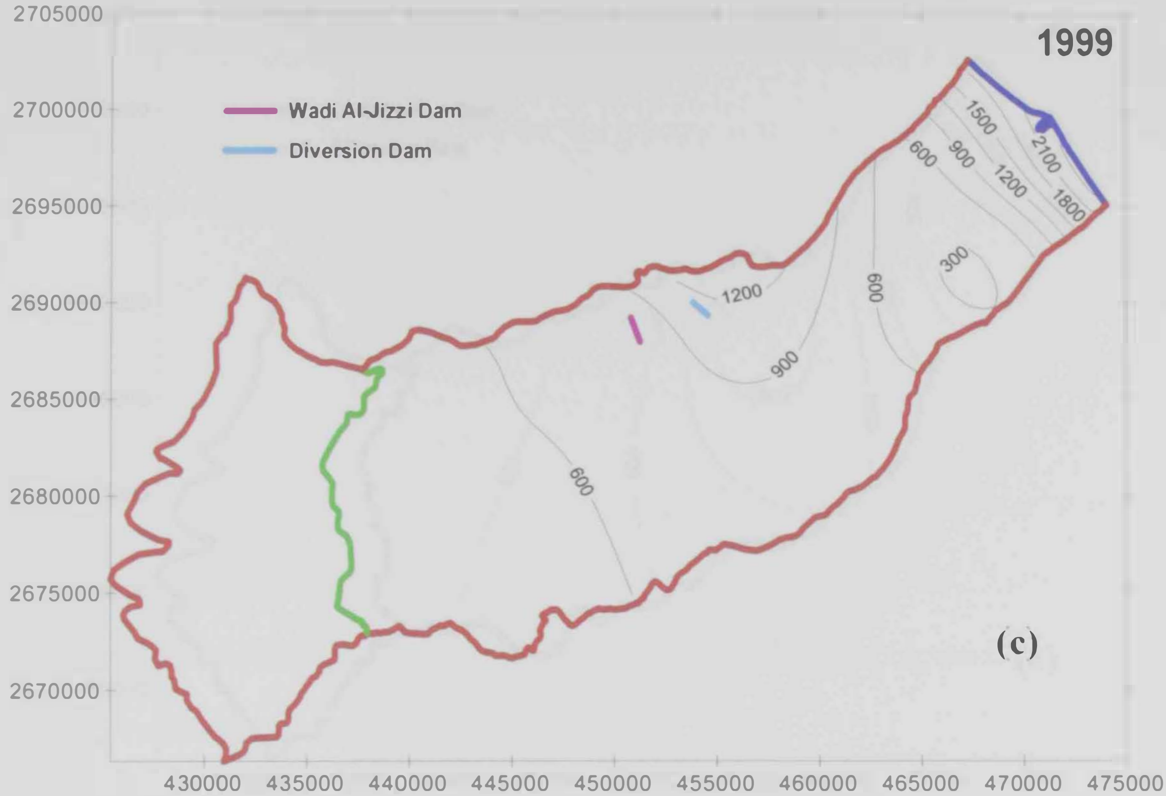


Figure 3.14. Measured total dissolved solids a) 1994, and b) 1997



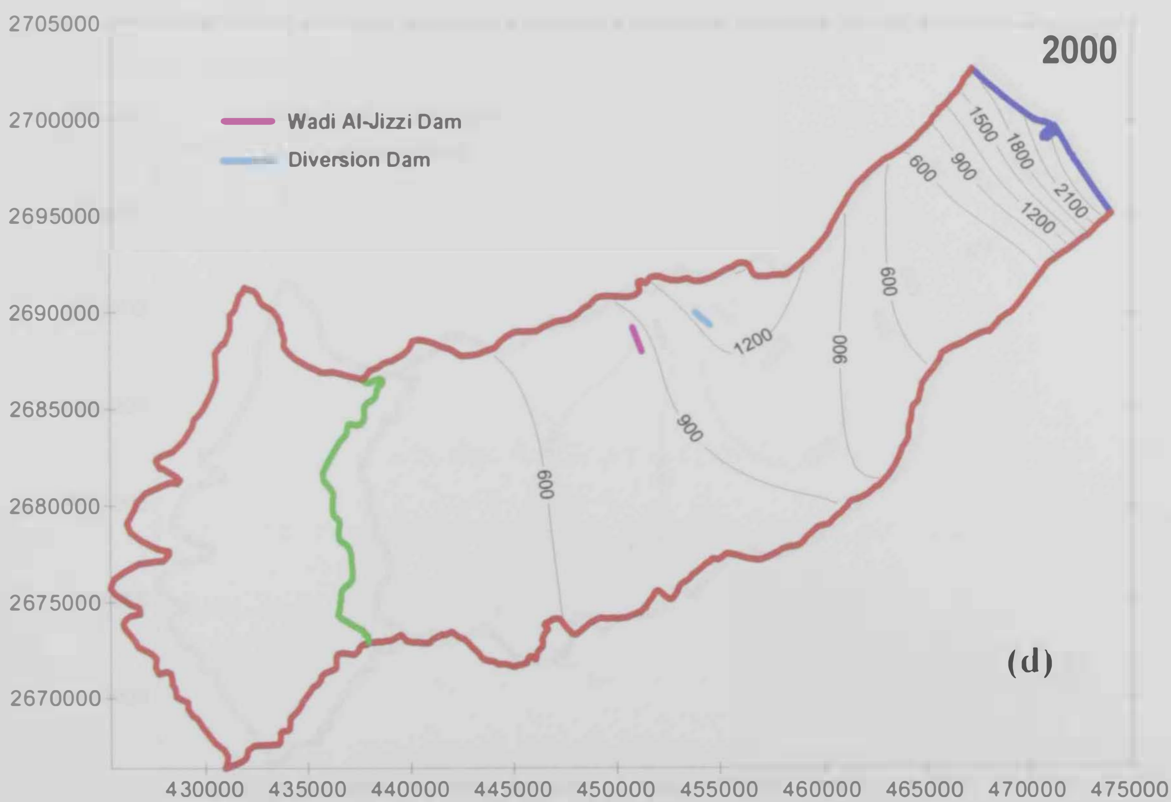


Figure 3.14 (continued). Measured total dissolved solids c) 1999, and d) 2000

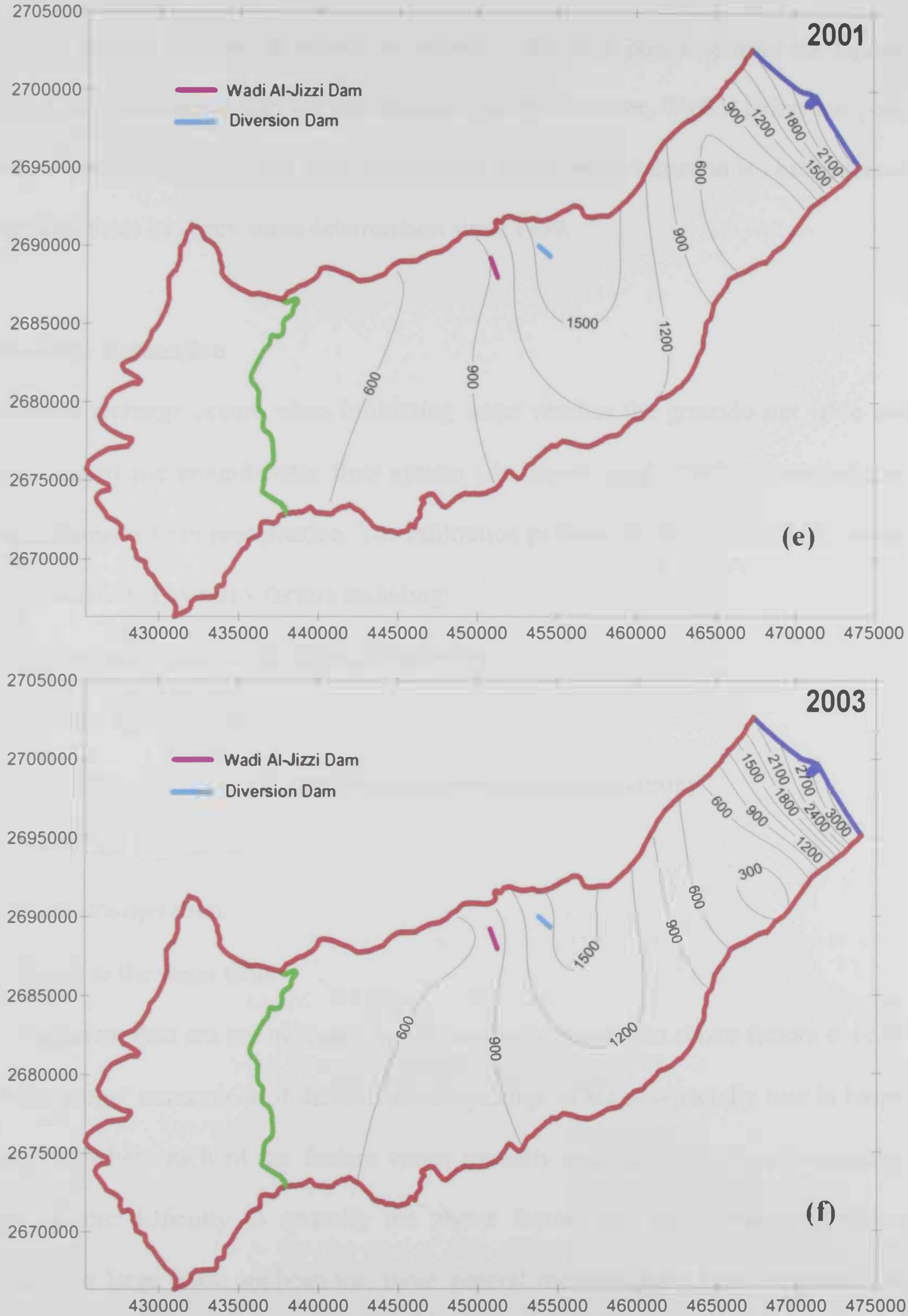


Figure 3.14 (continued). Measured total dissolved solids e) 2001, and f) 2003

increased to reach a value of 3300 mg/l. The equiconcentration contour line of 1500 moved inland to about 3.8 km from the coast line.

The gradual increase in salinity is related to the over pumping from the aquifer associated with less annual rainfall over the last 6 years. However, Wadi Al-Jizzi has good water quality as compared to the other catchments. Saline water intrusion is observed near the coast and there has been some deterioration since 1989.

3.7. Recharge Estimation

Groundwater recharge occurs when infiltrating water reaches the groundwater table and becomes part of the ground-water flow system (Anderson *et al.*, 1992). Essentially all recharge originates from precipitation. The infiltration process of precipitation to the water table can be affected by many factors including:

- Precipitation volume, duration and intensity
- Incident soil moisture
- Soil lithology, structure, chemistry, permeability and anisotropy
- Slope and vegetation
- Evapotranspiration
- Depth to the water table

Sufficient data are not available for all areas to evaluate the above factors in order to provide proper assessment of the volume of recharge. This is especially true in basin-wide studies where each of the factors varies spatially and, in many cases temporally. Because of the difficulty to quantify the above factors and their interrelationships, particularly in large scale applications, three general methods have been developed by hydrogeologists to estimate recharge. These are: 1) water budget, 2) percentage of precipitation and 3) geochemical techniques.

The Ministry of Water Resources (1999) grouped the hydrological catchments of the country into a number of Water Management Areas (WMA) and assessed the existing water situation and its relation with the agricultural distribution in Oman through the National Water Resources Master Plan. This Plan assumes the recharge rates on the average rainfall of 120 mm/year in Wadi Al-Jizzi lower catchment (about 519.69 km^2) and the average annual recharge about 26.79 MCM per year. Therefore, the average annual infiltration in m/y is:

$$\frac{26.79 \times 10^{6}}{519.7 \times 10^{6}} = 0.05155 \text{ m/year}$$

Since the average annual rainfall in Oman is 0.12 m, the percentage of recharge in Wadi Al-Jizzi catchment area as compared to the annual rainfall is equal to:

$$\frac{0.05155}{0.12} \times 100 = 43\%$$

Thus about 57 % of the rain water is lost either by evaporation or flood to the sea.

3.8. Discussions

The contour maps of groundwater levels and groundwater quality have shown a sort of stability in water levels in the upper part of the lower Jizzi catchment and an increase of salinity in year 2003 as compared to previous years. The lower Jizzi catchment area has experienced significant deterioration in groundwater quality but the most affected area is located between the highway and the coast line.

Generally the recharge originates from the Jizzi west side and from dam area and moves slowly to the aquifer in the east side of the catchment. The groundwater takes time to reach the coastal plain aquifer since the larger amount of recharge taking place through the main Wadi Al-Jizzi channel line. This contributes to the recovery of groundwater in the wells located down side of the recharge dam of Wadi Al-Jizzi in the north side of the aquifer. This may justify the water level rise in that part of aquifer and can be seen after 1997 flood that caused the increase of water levels in the year 1999.

It is therefore adequate to conclude that the dam has achieved a kind of groundwater balance that occurred in Wadi Al-Jizzi aquifer. Salinity studies showed that it is the least affected aquifer by seawater intrusion in the north of Al Batinah Coastal Plain (MWR, 1992). The dam provided up to 116.44 MCM of recharge to the groundwater since its construction in 1989.

Chapter 4. Groundwater Modeling in Wadi Al-Jizzi Catchment

4.1. Problem Statement and Study Area

Demand of water has increased proportionately along with the industrial and commercial development and population growth in Sultanate of Oman. Oman lies in an arid region with irregular and insufficient rainfall. Economical growth has increased the living standards causing an even higher water demand.

Groundwater is the main source of fresh water. Although desalination plants meet the drinking water demand to a small scale, the main pressure on groundwater remains almost unchanged. Due to the imbalance between resource and demand groundwater levels are continuously declining in most of the catchments. As a result seawater intrusion is taking place causing another major threat to the limited freshwater resources of the country.

Many studies have been undertaken in the past to resolve this problem. One of the protective measures was the construction of recharge dams. Several dams were constructed during the 1980s to control and capture surface runoff to the sea and increase groundwater recharge. Wadi Al-Jizzi dam was one of them. In this study a numerical model has been developed for wadi Al-Jizzi catchment to assess pre/post dam situation of groundwater. This study also simulates a future scenario of no intervention for the year 2020.

Wadi Al-Jizzi catchment is located in the northern part of Oman. The total drainage area of the catchment is about 1050 km^2. About 730 km^2 is exposed bedrock with little soil and 320 km^2 is alluvium (DGWRA, 1995). The catchment can be subdivided into two main physiographic units; 1) the Hajar Al Gharbi mountain highlands which form the upper catchment, and 2) the lower catchment within the Batinah plain. About 812 km^2

is above the Wadi Al-Jizzi Dam most of which is covered by the mountain highland. Below the Wadi Al-Jizzi Dam, flood water released from the dam pass downstream to be diverted by a diversion dam, which concentrates flow to the main wadi channels. Excess outflows ultimately enter the Gulf of Oman. Higher elevations occur in the northwest and southwest parts of the catchment with a maximum elevation of 1602 masl in the Wadi Kitnah sub-catchment. Wadi Al-Jizzi is different from most of the other North Batinah catchments in that the Wadi penetrates for a considerable distance to the west through a narrow gap in the mountains (Cansult, 1998).

The wadi channel is steeply incised into the base of a narrow valley in the eastern part of the upper catchment. The valley widens to the west near Al Wasit. The Wadi channels are typically comprised of coarse alluvium. In the west, the recent Wadi deposits are flanked and often underlain by older, cemented alluvial terrace deposits.

The Wadi exits the mountains at Al Mulaynah and enters the lower part of the catchment on the Batinah plain. The piedmont plain has an average slope of 0.009. The Wadi branches out into a network of braided channels. Further east, the Wadi enters the coastal plain which has gentle to flat slopes. The Wadi channels eventually converge near the main highway and cross 2.5 km wide coastal strip. This strip has good soil and is irrigated mostly by dug wells. The Wadi discharges to the Gulf of Oman at Ras Sallan (Cansult, 1998).

4.2. Data Availability

Most of the required data have been collected from Ministry of Municipalities, Environment and Water Resources (MRMEWR). Some data were also collected from other organizations and published papers and reports.

4.2.1. Rainfall

Data of seven rainfall stations have been collected out of which 3 stations falls in the upper catchment, 2 just below the upper catchment and 2 in the coastal plain. The locations of these stations are shown in Figure 4.1 and are tabulated in Table 4.1.

Table 4.1. Rainfall data

Site ID	Local ID	East	North	Available Data	
				From	To
DM580942AF	AL JIZZI NEAR DAM	450426	2689150	1973	2001
DM476902AF	L'AQAQ AT L'AQAQ	446042	2679166	1974	2001
DM382737AF	HAYL AL ADHAH 1 AT HAYL AL ADAH	432725	2688533	1982	2001
DM383052AF	AL KHAN NEAR AL KHAN	433765	2680444	1993	2000
DM374569AF	AL FAR FAR AT AL FAR FAR	434598	2675921	1977	2001
DM792227BF	SOHAR 2 AT SOHAR	472200	2692700	1977	2001
DM688469AF	AL MOUWAYLIH AT AL MOUWAYLIH	468600	2684900	1993	2003

Table 4.2. Wadi flow data

Station	Site ID	Easting	Northing	Record From	Record To
Jizzi Near Sohar	DB698772AD	468700	2697200	1984	2002
Jizzi Mulayinah	DB388507AD	438000	2685700	1982	2002

4.2.2. Wadi flow

Regular measurements are recorded in the two wadi gauge stations in the study area of Wadi Al-Jizzi catchment. Wadi gauge at Mulainih is located at the upper catchment and Wadi guage at Sohar is at the coastal plain. The locations of these gauges are shown in Figure 4.1 and Table 4.2.

4.2.3. Groundwater monitoring

Water levels are being monitored at thirty seven boreholes in the study area of the Wadi Al-Jizzi catchment. The locations are shown in Figure 4.1. The details of data availability for monitoring wells are summarized in Table 4.3.

Figure 4.1. Location of Available Data Measurement Stations

Table 4.3. MRMEWR monitoring wells data record

Monitoring Stations			Data Availability	
Local ID	Easting	Northing	From	To
MS-2	442187	2685370	1982	2002
WJ-4	441605	2686977	1982	2002
W-1	446260	2686004	1982	1999
OA-1	456738	2690876	1982	2000
JA-04	461338	2695598	1985	2002
EA-1	466729	2692859	1982	2002
JA-02	468668	2696578	1985	2002
SALLAN	471938	2697460	1983	2002
DE-4	466872	2695192	1989	2002
GHJ-7	451073	2688504	1993	1999
MULTAQAH	466772	2700835	1994	2000
NJ-3	463269	2688755	1990	2001
HS-12	464244	2698107	1986	2002
DE-2	465025	2694844	1989	2002
DE-5	466905	2694224	1989	2002
BD88268	470849	2695965	1994	2001
DEO-10	470264	2697926	1989	1998

4.2.4. Dam reserve

The data of Wadi Al-Jizzi recharge dam was available from 1982 to 2002. Dam inflow and outflow data have been used to estimate recharge.

4.2.5. Well abstraction

Wells data and discharge data collected from National Well Inventory (NWI) database and SDO. There are 3667 inventoried NWI wells which have been incorporated in the model.

Estimated yearly abstraction was available as yearly net demand. As per the NWI report the irrigation return has been deducted from demand to calculate net demand. Therefore, irrigation return from these wells has not been considered in the model. The yearly demand has been distributed between summer and winter. SDO has 8 abstraction wells. Monthly abstraction data were available for these wells. Therefore, monthly abstraction rate has been used for these wells. The locations of these wells are shown in Figure 4.2.

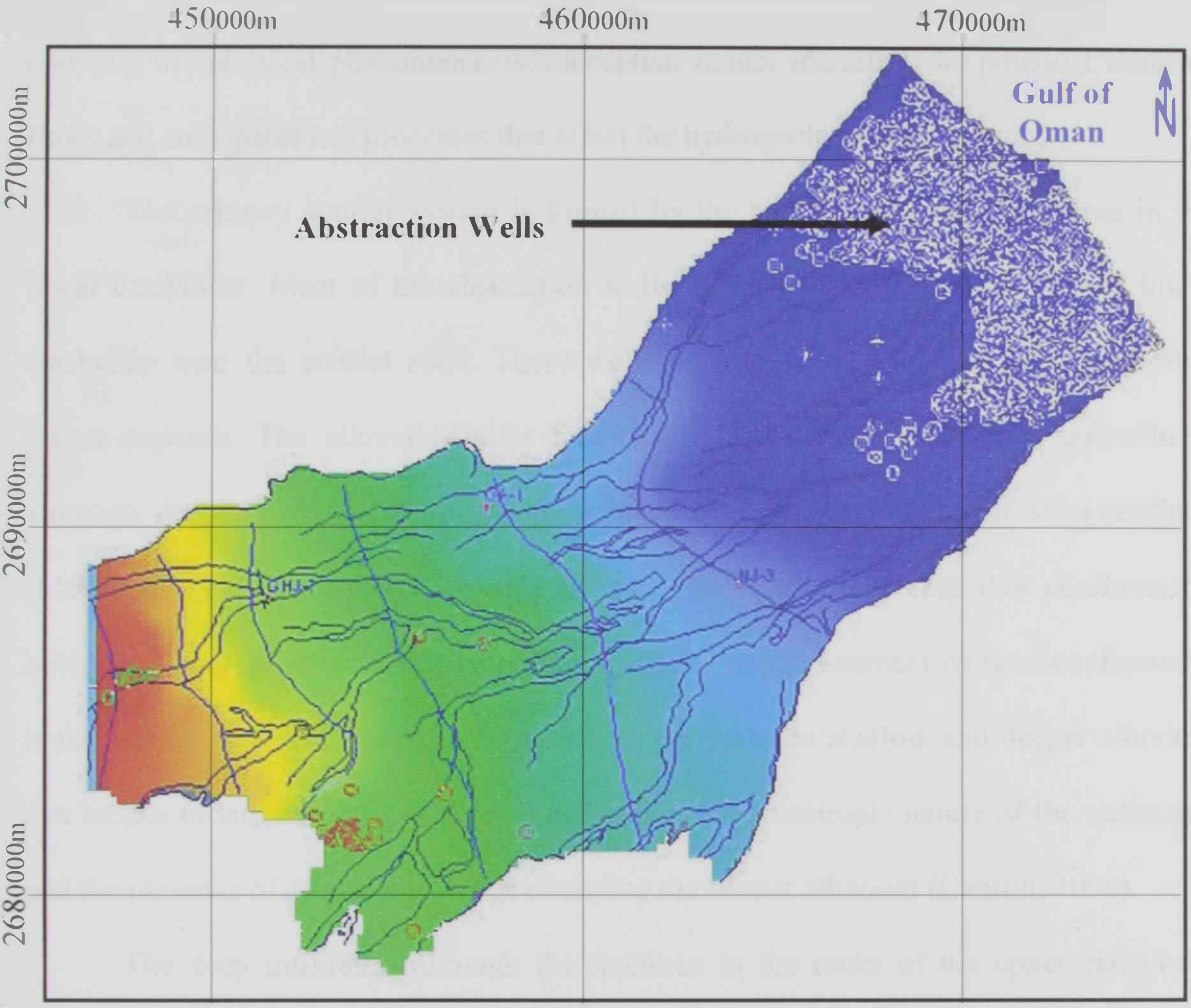


Figure 4.2. Locations of abstraction wells

4.3. Conceptual Model

The conceptual model identifies potential flow pathways and anticipates key processes that affect site hydrogeology. Careful development of the conceptual model is needed to streamline the remaining steps of the modeling process. Conceptualization of the potential processes is based on few assumptions that lead to development of modeling exercises for realizing the physical phenomena. A conceptual model identifies the potential route of flows and anticipates key processes that affect the hydrogeology of the region.

The primary aquifer system is formed by the ancient and recent alluvium in the lower catchment. Most of the abstraction wells in the catchment are also in the lower catchment near the coastal zone. These wells exploit water from the more permeable recent deposits. The alluvial aquifer formed by these recent deposits is unconfined, although deeper parts of the alluvium seem to behave as confined or semi-confined (McDonald, 1997). A modeling attempt was made to incorporate this confinement, however it was unsuccessful revealing the fact that the confinement or semi-confinement is not continuous. The observed head differences between shallow and deeper alluvium can be due to laterally extensive cemented zones, the anisotropic nature of the sediments and the presence of a saltwater wedge overlying the deeper alluvium (Cansult, 1998).

The deep infiltration through the fractures in the rocks of the upper catchment contributes to the aquifer system of the lower catchment as upward seepage from the bedrock. This upward seepage has been taken into account in the model by creating a higher head second layer.

Under pre-development conditions, discharge from the alluvium occurred primarily through evaporation at sabkhahs, evapotranspiration in areas of shallow water table, and by direct discharge to the sea. Under current conditions, however, consumptive use for irrigation and other domestic and industrial purposes is now the primary mechanism of groundwater discharge (Cansult, 1998).

Regional flow is generally from the piedmont zone in the west towards the coast. Rates of flow are primarily controlled by the rate of distribution of recharge and discharge and by the distribution of hydraulic conductivity. Regional gradients are steeper in the west and become much shallower as the alluvium thicken towards the coast.

4.3.1. Model domain

Selection of the model domain depends on the geology, hydrogeological interest and availability of data. For this study the model domain has been selected from end of the impermeable bedrock to eastern coast line. The entire Western part of the upper catchment is not included in the model domain as most of the Western part of the catchment is covered by impermeable rock which is termed as no flow boundary in groundwater modeling. Recharge component includes the surface runoff from the upper catchemnt. The through flow from the upper catchment has been considered by constructing a general head boundary. The selected model area extends from 445000m to 475000m easting and from 2672700m to 2702700m northing in UTM coordinate system, Figure 4.3.

4.3.2. Model grid

Finite difference models are easier to program, require less data and are more friendly for data input (Kresic, 1997). Therefore, a square finite difference grid has been used. The whole area has been divided into 200m by 200m grids resulting in 150 columns, 150 rows and 22500 cells per layer. Cells in the grid which fall outside the catchment are designated as "inactive". Also, the impermeable rocks in the upper catchment are designated by

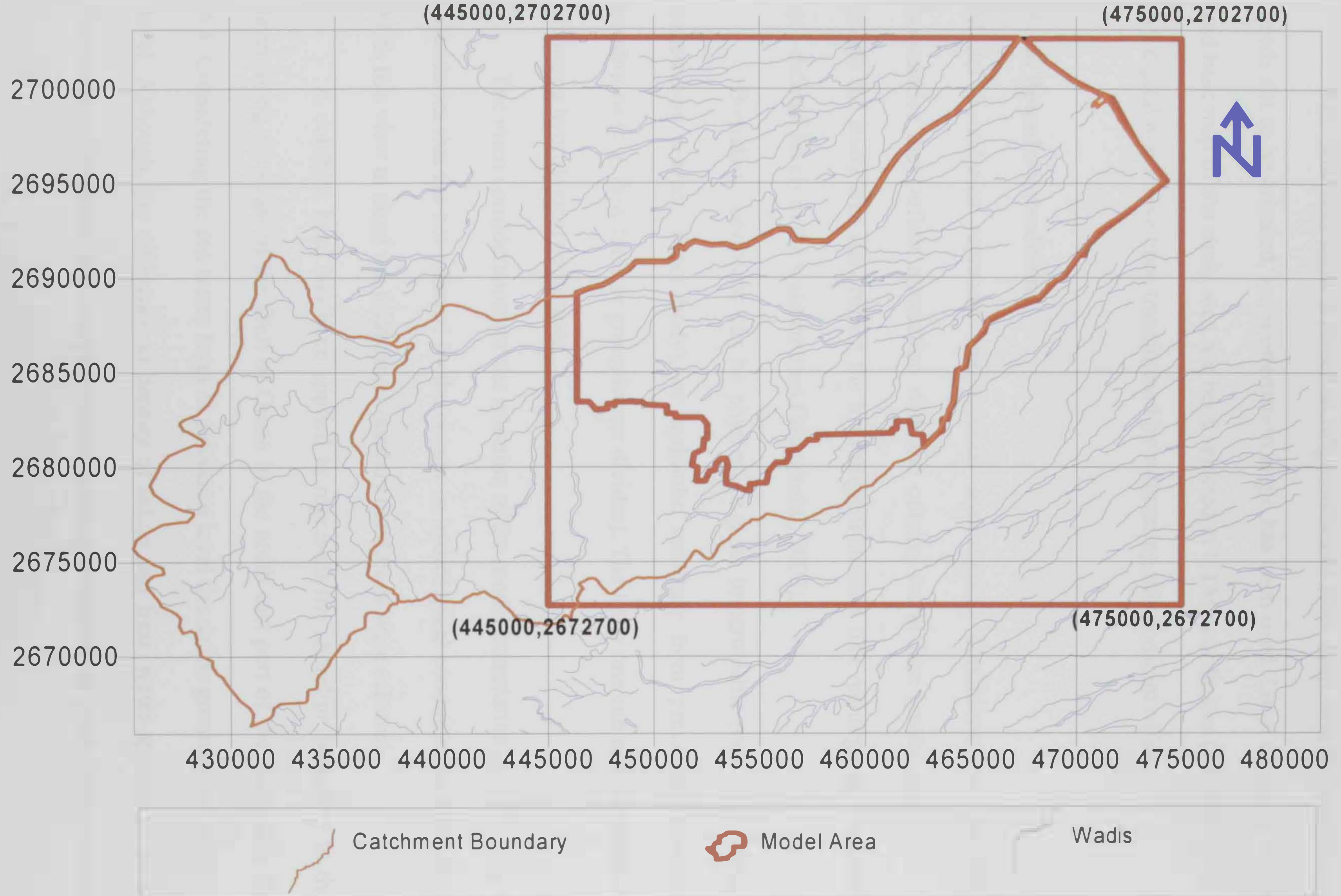


Figure 4.3. Mdel domain

inactive cells. These inactive cells do not contribute to groundwater flow and remain out of the model simulation.

The flow nets show a direction of groundwater flow from west to east. The model needs not to be oriented, i.e. 0 orientation angle has been used. Local origin of the model and base map of the study area has been selected at UTM coordinates (445000, 2672700). All digital maps have been transformed by subtracting this constant offset.

4.3.3. Boundary conditions

Model boundaries represent the external hydrological conditions. At the physical boundaries they reflect interaction with the outside world like levels, flows etc. while inside the study area they reflect the hydrological stresses like recharge, abstractions and pre-defined levels in the watercourses (Muzahidul, 2002).

Boundary conditions can be physical (e.g. an impermeable rock or a large, fully penetrating surface water body), or hydraulic resulting from prevailing hydrological conditions (e.g. flow lines or groundwater divides). The latter one can shift in space due to changing hydrological conditions.

The main consideration for the selection of the model boundaries is to obtain a set of boundaries that are not affected by the change in hydrological conditions in the study area. With this view in mind the following boundary conditions were selected.

A constant head has been applied to represent the shoreline boundary in the top layer along the coast of the Gulf of Oman in the north east part of the catchment, Figure 4.4. Considering the sea water level as reference level the saline groundwater head is at 0 level. Although, the difference in density of saline and fresh water appears to be small, they have a significant effect on piezometric heads and thus on the groundwater system.

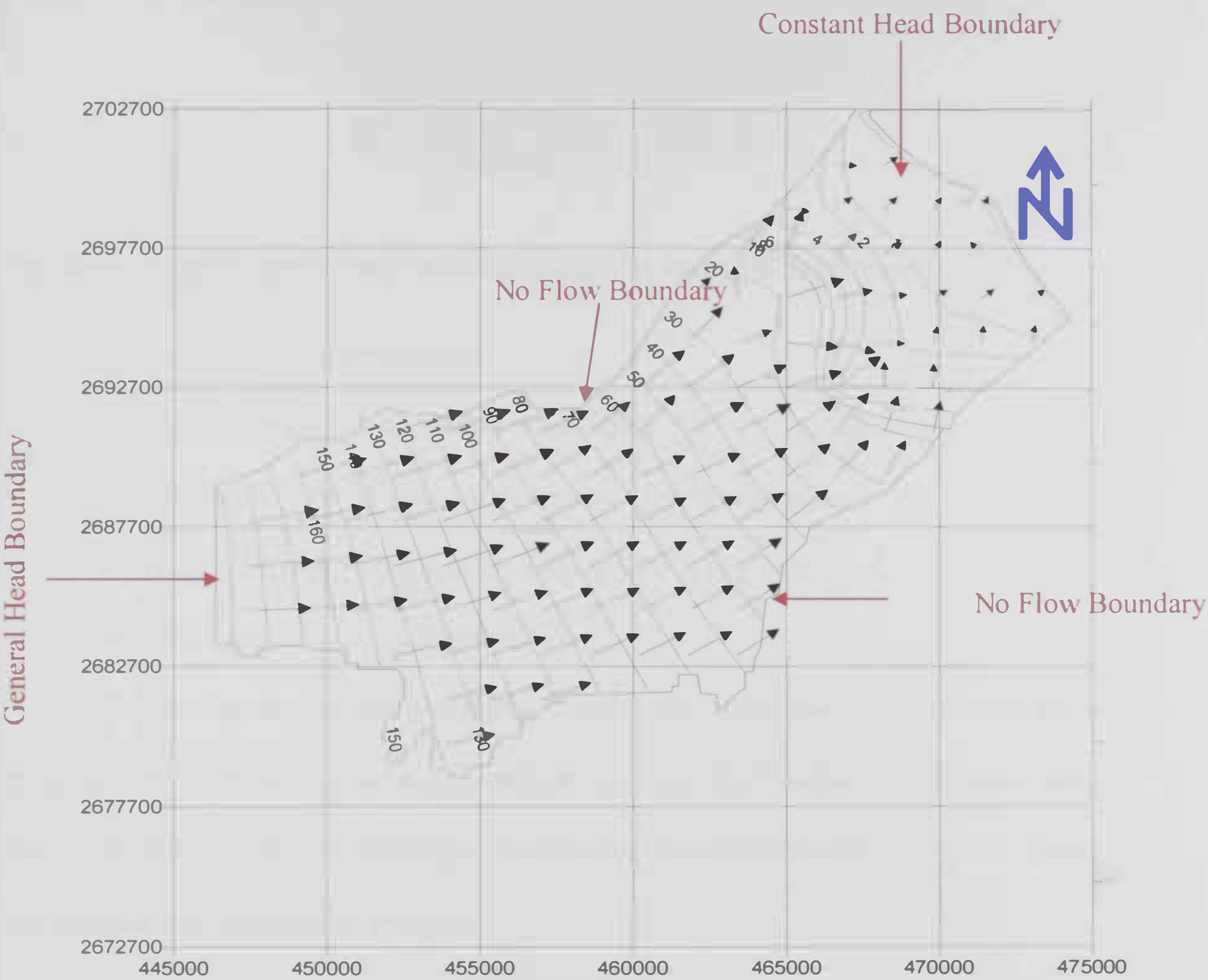


Figure 4.4. Model boundaries

Hence, the head is adjusted on the basis of the Badon Ghijben (1889)-Herzberg (1901) principle, Figure 4.5. The pressure of saline water body is equal to the pressure the of fresh water body.

$$\rho_s Hg = \rho_f (H + h) g \Rightarrow \rho_s H = \rho_f H + \rho_f h$$

$$h = \frac{\rho_s - \rho_f}{\rho_f} H$$
$$h = \alpha H$$

The above principle should only be applied under the following conditions:

- The aquifer is homogeneous,
- The hydrodynamic dispersion is negligible,
- Vertical flow in the aquitard, horizontal flow is negligible,
- Horizontal flow in the aquifer, vertical flow is negligible,
- Saline groundwater is at rest: $q_s = 0$

This largely satisfies the prevailing local aquifer conditions. Following the above principle, the saline water head is adjusted (the centre of the boundary cell of each layer). For ρ_s=1025 kg/m^3 and ρ_f=1000 kg/m^3 the relative density difference is α=0.025. Hence, the adjusted head for any cell becomes:

$$h_f = (1 + \alpha) H$$

No flow boundaries

No flow boundaries are special type of specified flow boundaries where the flow rate across the boundary is assumed zero throughout the entire simulation period. In this study two types of no flow boundaries have been assumed, physical and hydrological. Physical no flow boundary occurs when a large impermeable rock exists. Most of the upstream part

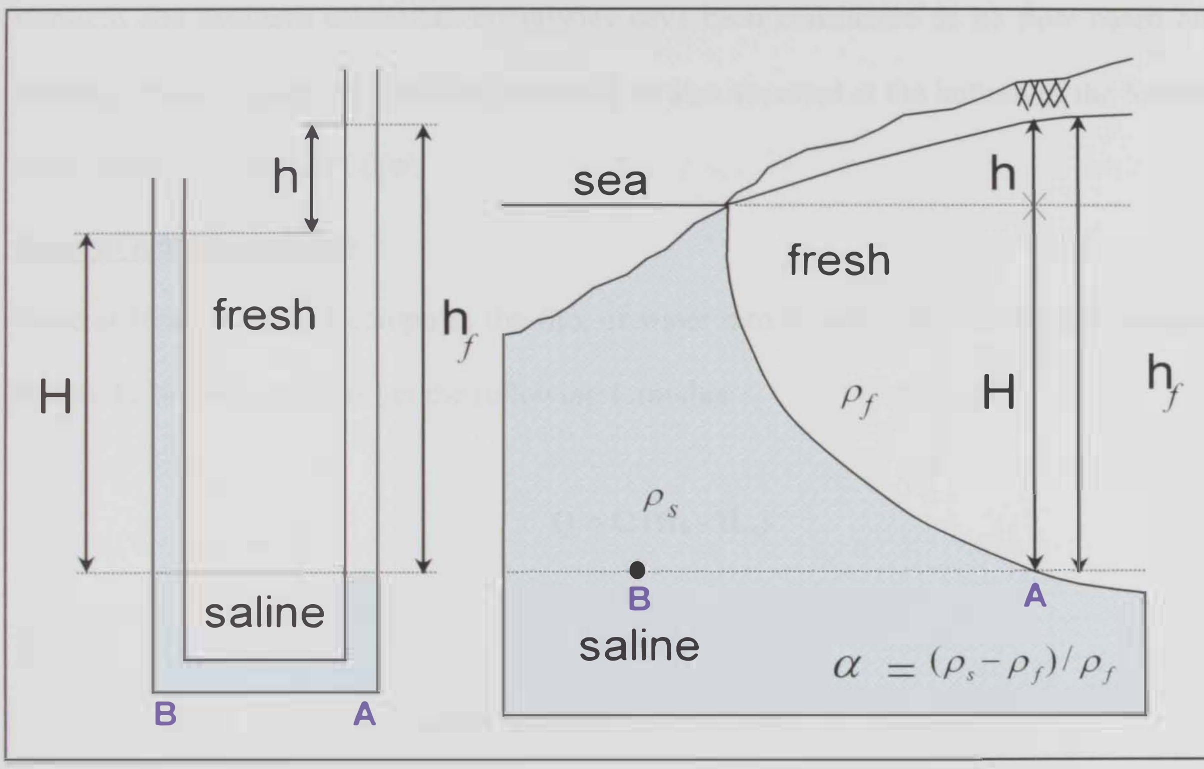


Figure 4.5. Fresh-salt interface in an unconfined coastal aquifer (Muzahidul, 2002)

of the catchment is covered by impermeable rock. Therefore, the western boundary of the model has been considered from end of the hilly upper catchment. The rock area of southwest corner of the catchment has been defined by inactive cells, Figure 4.4.

Hydrological no flow boundary is decided based on prevailing hydrological conditions such as flow lines and phreatic divide. Water table contour map shows a gradient from west to east indicating the direction of groundwater flow. Therefore, the northern and southern catchment boundaries have been considered as no flow based on phreatic divide, Figure 4.4. No flow boundary is also assumed at the bottom of the lowest layer (layer 2) by MODFLOW.

General head boundaries

General Head Boundary computes the flux of water into or out of the model and assigns that to the boundary cell as per the following formulae:

$$Q = C\,(H_b - H_m)$$

Where,

Q	=	Flux into or out of boundary cell, (L^3/T)
H_b	=	Boundary head, (L)
H_m	=	Head computed by model, (L)
C	=	Boundary conductance = K_bA/B, (L^2/T)
K_b	=	Hydraulic conductivity of the boundary material, (L/T)
A	=	Area of the boundary cell, (L^2)
B	=	Thickness or width of boundary, (L)

To estimate the through flow from the upper catchment into the model domain a general head boundary has been created along alluvium part of the western boundary, Figure 4.4. Initially, general head boundaries were also considered along downstream part of the northern and southern boundary to consider any through flow from or to the neighbouring catchments. However, model results showed very small variation with or without these general head boundaries. Therefore, at a later stage, these general head boundaries have been removed.

4.3.4. Simulation Period

Based on the availability of data the simulation period has been selected from January 1985 to December 1994. The reason behind the selection of such a long simulation period is to cover both dry and wet years so that model response in different hydrological years and conditions can be validated. The long simulation period also stabilizes the initial fluctuations due to errors in starting hydraulic head.

The transient flow model is a compromise between steady and full temporal unsteady flow. It divides the total simulation time of the model into a number of stress periods. Various hydrological conditions can be set for subsequent stress periods. The stress periods are chosen such that the hydrological stresses can be considered as constant throughout a stress period. Actually, this is sequentially connecting a number of different steady hydrological stresses at different time periods.

To incorporate the variation of hydrogeological stresses over time, the 10 years simulation period has been divided into 198 number of stress periods. The length of the stress periods have been decided based on the Wadi flow. When the wadi flows the stress period length has been chosen equal to the number of days of the flow while longest stress period has been chosen 1 month during the no flow period. Table 4.4 illustrates how the stress periods have been considered. The full table is presented in Appendix E.

Table 4.4. Selection of stress periods (Example, see Appendix E for full stress periods details)

Stress Periods	From	To	days	Mulaina Flow (m3/d)	Mulaina Flow (m3)
1	1/1/1985	1/31/1985	31	0	0
2	2/1/1985	2/28/1985	28	0	0
3	3/1/1985	3/31/1985	31	0	0
4	4/1/1985	4/30/1985	30	0	0
5	5/1/1985	5/31/1985	31	0	0
6	6/1/1985	6/30/1985	30	0	0
7	7/1/1985	7/31/1985	31	0	0
8	8/1/1985	8/31/1985	31	0	0
9	9/1/1985	9/30/1985	30	0	0
10	10/1/1985	10/31/1985	31	0	0
11	11/1/1985	11/30/1985	30	0	0
12	12/1/1985	12/31/1985	31	0	0
13	1/1/1986	1/31/1986	31	0	0
14	2/1/1986	2/1/1986	1	58200	58200
15	2/2/1986	2/28/1986	27	0	0
16	3/1/1986	3/31/1986	31	0	0
17	4/1/1986	4/30/1986	30	0	0
18	5/1/1986	5/31/1986	31	0	0
19	6/1/1986	6/30/1986	30	0	0
20	7/1/1986	7/11/1986	11	0	0
21	7/12/1986	7/15/1986	4	25462.75	101851
22	7/16/1986	7/31/1986	16	0	0
23	8/1/1986	8/31/1986	31	0	0
24	9/1/1986	9/30/1986	30	0	0
25	10/1/1986	10/12/1986	12	0	0
26	10/13/1986	10/14/1986	2	14002	28004
27	10/15/1986	10/21/1986	7	0	0
28	10/22/1986	10/25/1986	4	8469.75	33879
29	10/26/1986	10/27/1986	2	0	0
30	10/28/1986	10/31/1986	4	10708.5	42834
31	11/1/1986	11/30/1986	30	0	0
32	12/1/1986	12/31/1986	31	0	0
33	1/1/1987	1/31/1987	31	0	0
34	2/1/1987	2/20/1987	20	0	0
35	2/21/1987	2/22/1987	2	55289	110578
36	2/23/1987	2/28/1987	6	0	0
37	3/1/1987	3/13/1987	13	0	0
38	3/14/1987	3/26/1987	13	81656.07692	1061529
39	3/27/1987	3/31/1987	5	357216.6	1786083
40	4/1/1987	4/6/1987	6	28286.33333	169718
41	4/7/1987	4/14/1987	8	375361.375	3002891
42	4/15/1987	4/30/1987	16	2062.5	33000
43	5/1/1987	5/30/1987	30	1766.666667	53000

4.4. Programming Code and Software Package

Selection of a suitable computer program and pre and post processing software package is a pre-requisite of modeling. MODFLOW has been used as a computer program for this study. MODFLOW simulates groundwater flow in three dimensions using finite-difference techniques to solve the partial differential equation describing ground-water movement (McDonald and Harbaugh, 1988). MODFLOW88 was developed in the early 1980's and has continually been updated since then with development of many new packages and related programs for groundwater studies. MODFLOW2000 is the latest release of US Geological Survey's modular groundwater flow model. It is a three dimensional finite difference model capable of simulating both transient and steady state flow in confined or unconfined aquifer systems.

The computer code is widely recognized and has been tested and validated worldwide. The popularity of the program is attributed to the following factors (http://water.usgs.gov):

- The finite-difference method used by **MODFLOW** is relatively easy to understand and apply to a wide variety of real-world conditions.
- **MODFLOW** works on many different computer systems ranging from personal computers to super computers.
- **MODFLOW** can be applied as a one-dimensional, two-dimensional, or quasi-or full three-dimensional model.
- The modular program design of **MODFLOW** allows for new simulation features to be added with relative ease.
- A wide variety of Pre and Post Processor computer programs written by the USGS, other federal agencies, and private companies are available to analyze field data and construct input data sets for **MODFLOW**.

A wide variety of programs are available to read output from MODFLOW and graphically present model results in ways that are easily understood.

4.4.1. Simulation capabilities of MODFLOW

MODFLOW is a computer program that numerically solves the three-dimensional groundwater flow equation for a porous medium by using a finite-difference method (Al-Shibli, 2002). It is designed to simulate aquifer systems in which (1) saturated-flow conditions exist, (2) Darcy's Law applies, (3) the density of groundwater is constant, and (4) the principal directions of horizontal hydraulic conductivity or transmissivity do not vary within the system. These conditions are met for many aquifer systems for which there is an interest in analysis of groundwater flow and contaminant movement. For these systems, MODFLOW can simulate a wide variety of hydrologic features and processes. Steady-state and transient flow can be simulated in unconfined aquifers, confined aquifers, and confining units (http://water.usgs.gov).

A variety of features and processes such as rivers, streams, drains, springs, reservoirs, wells, evapotranspiration, and recharge from precipitation and irrigation can also be simulated. At least four different solution methods have been implemented for solving the finite-difference equations that MODFLOW constructs. The availability of different solution approaches allows model users to select the most efficient method for their problem (http://water.usgs.gov).

4.4.2. Application of MODFLOW

MODFLOW simulates groundwater flow in aquifer systems using the finite-difference method. In this method, an aquifer system is divided into rectangular blocks by a grid. The grid of blocks is organized by rows, columns, and layers, and each block is commonly called a "cell".

4.4.3. MODFLOW input

For each cell within the volume of the aquifer system, the user must specify aquifer properties. Also, the user specifies information relating to wells, rivers, and other inflow and outflow features for cells corresponding to the location of the features. For example, if the interaction between a river and an aquifer system is simulated, then for each cell traversed by the river, input information includes layer, row, and column indices; river stage; and hydraulic properties of the river bed (http://water.usgs.gov).

4.4.4. MODFLOW output

MODFLOW uses the input to construct and solve equations of groundwater flow in the aquifer system. The solution consists of head (groundwater level) at every cell in the aquifer system (except for cells where heads are specified as known in the input data sets) at intervals called "time steps." The head can be printed and (or) saved on a computer storage device for any time step. Hydrologists commonly use water levels from a model layer to construct contour maps for comparison with similar maps drawn from field data. They also compare computed water levels at individual cells with measured water levels from wells at corresponding locations to determine model error. The process of adjusting the model input values to reduce the model error is referred to as model calibration.

In addition to water levels, MODFLOW prints a water budget for the entire aquifer system. The budget lists inflow to and outflow from the aquifer system for all hydrologic features that add or remove water.

Other program output consists of flow rates for each model cell. MODFLOW can write the flow rates onto a computer storage device for any hydrologic feature in a simulation. These cell-by-cell flow rates commonly are read by post-processing programs for detailed analysis of the simulated groundwater system (http://water.usgs.gov).

4.5. Hydrogeological Framework and Stresses

Groundwater is abstracted by wells, which is compensated by rainfall, irrigation return, open water infiltration etc. The driving force of all these activities are surface topography, soil characteristics, aquifer parameters, groundwater abstraction pattern etc. Modeling requires to identify and quantify all these driving forces.

4.5.1. Processing aquifer elevations

Defining Aquifer elevations is the first step in Model Setup. Aquifer elevations have been decided based on the previous study reports and drilling logs on the study area. Unfortunately, no much useful information could be collected. Cansult (1998) provided a cross section which was used as a basis of layer selection. Few drilling logs were available in JICA (1985). Elevations of the aquifer have been prepared for model input by interpolating data at these selected points using Kriging's method.

Ground level elevation has been prepared from the monitoring station data. Each monitoring station had measuring point elevation from which 0.5 m has been deducted to get ground level elevation. However, MODFLOW concentrates on saturated zone only. Therefore, GL elevation is not very important and can be approximated without affecting the output, Figure 4.6a. Vertical extent of bedrock is undefined. Therefore, second layer of the model has been prepared by considering 50 m deep, Figure 4.6b. The contour lines of the aquifer thickness are presented in Figure 4.7.

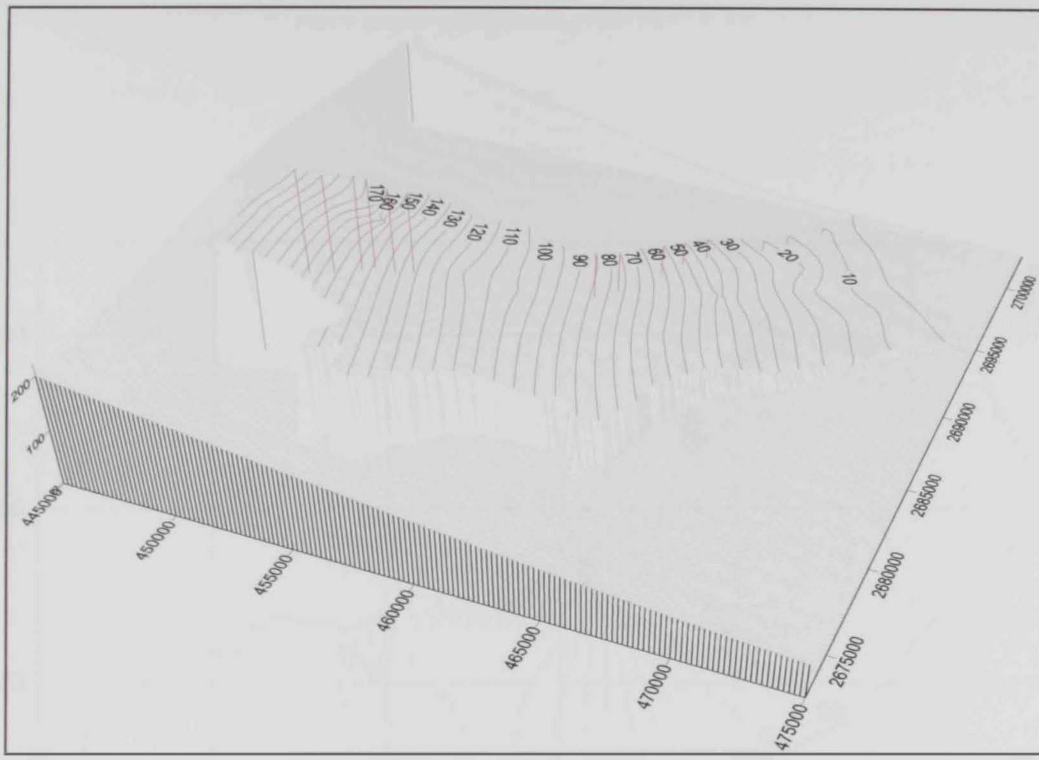


Figure 4.6a. Ground elevation of the study area

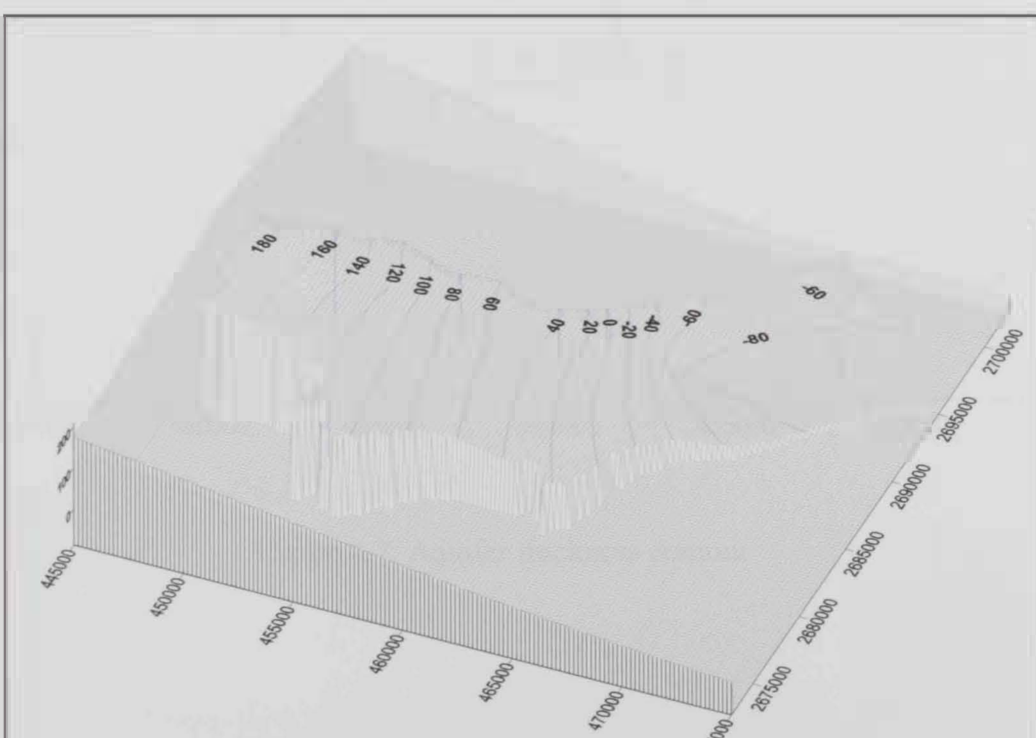


Figure 4.6b. Bedrock elevation

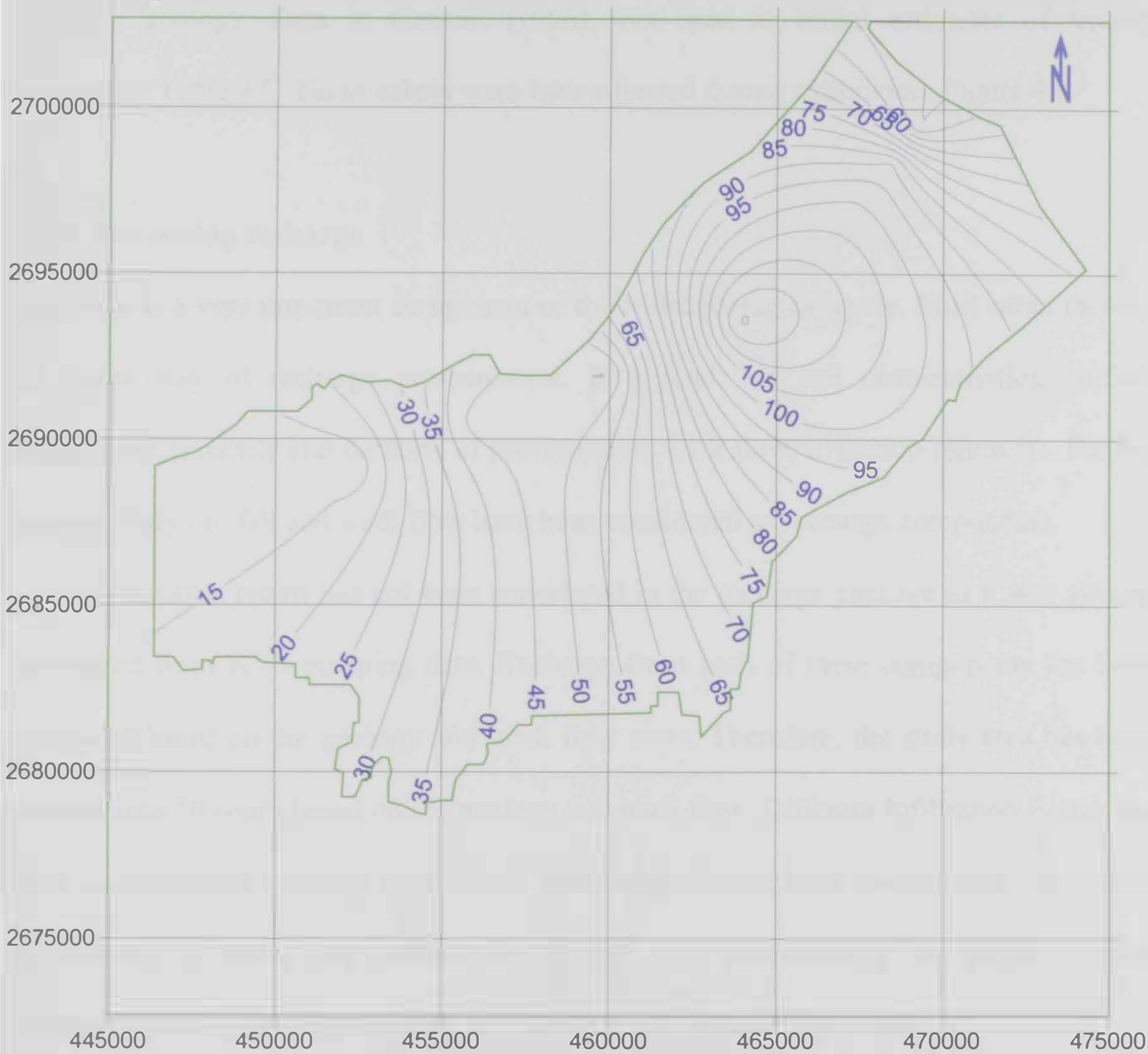


Figure 4.7. Aquifer thickness contour

4.5.2. Processing aquifer parameters

Once the layer elevations have been identified, the next step in model setup is to define aquifer parameters like Hydraulic Conductivity (K_x, K_y, K_z), Specific Storage (S_s), Specific Yield (S_y), Porosity etc. Initially, model area was divided into zones according to different geology. Data in Cansult (1998) was used as initial estimates of aquifer properties, Table 4.5. These values were later adjusted during calibration, Figure 4.8.

4.5.3. Processing recharge

Recharge is a very important component of the hydrogeological cycle. Most often there is no direct way of recharge measurement. It depends on soil characteristics, surface topography, intensity and duration of precipitation, wadi flow, irrigation return etc. For the present study rainfall and wadi flow have been considered as recharge components.

Irrigation return has not been considered in the recharge package as it was already subtracted from NWI pumping data. Recharge from each of these components has been estimated based on the geology and wadi flow zone. Therefore, the study area has been divided into 20 zones based on the geology and wadi flow. Different Infiltration Factor has been used for each recharge zone. These Infiltration Factors have been used as calibration parameters to adjust the estimated recharge. The methodology for recharge zone numbering and estimating recharge for those zones is presented hereafter.

Recharge zone numbering

Geological zones in Wadi Jizzi Catchment have been defined by the numbers given in Table 4.6. The wadi flow area has been defined by different zones based on location and geology. The numbering of zones that were used for wadi recharge area is given in Table 4.7. It was assumed that dam reservoir has higher recharge factor. Therefore, a separate zone (zone 10) has been created around dam area.

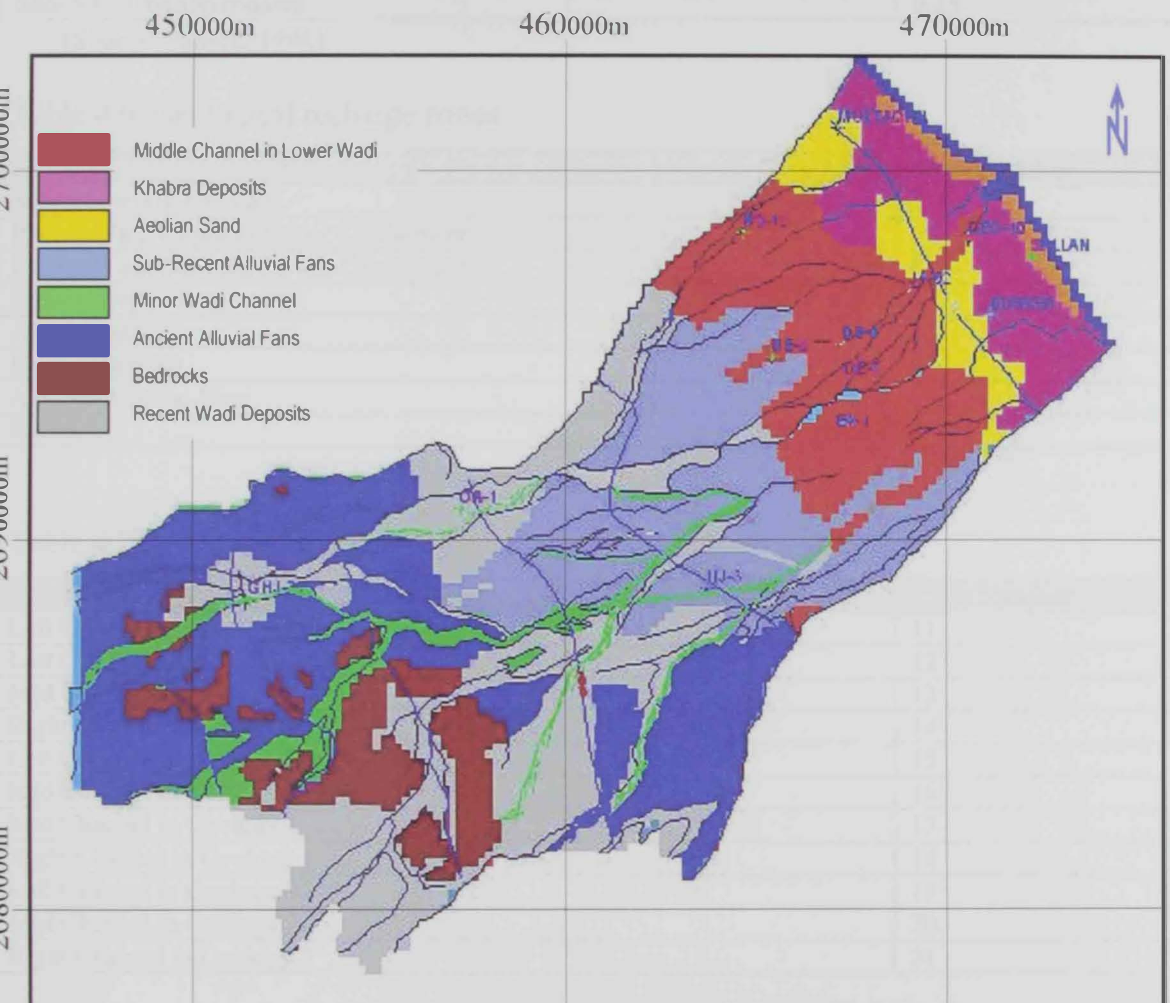


Figure 4.8. K zones in the model

Table 4.5. Initial estimates of K values for different zones

Surface Geology	K (m/d)
Recent Wadi Alluvium –Upper Catchment	60
Recent Wadi Alluvium –Coastal Plain	90
Coastal Deposits	150
Aeolin Sand	120
Khabra Deposit	150
Sub-recent Alluvial Fans	30
Ancient Alluvial Fans	2
Ancient Alluvial Terraces	2
Bedrock –Undifferentiated	0.25

(Source: Cansult, 1998)

Table 4.6. Geological recharge zones

Geology	Code Number
Sub-recent Alluvial Fans	1
Recent Wadi Deposits Upper Catchement	2
Recent Wadi Deposits Lower Catchement	3
Coastal Deposits	4
Aeolin Sand	5
Khabra Deposit	6
Ancient Alluvial Fans	7
Bedrock	8

Table 4.7. Wadi recharge zones

Wadi Area	Code Number
Left Channel before Dam	11
Left Channel in Geology 7 after Dam	12
Mid Channel in Geology 7	13
Right Channel in Geology 7	14
Left Channel in Geology 2	15
Mid Channel in Geology 2	16
Mid Channel in Geology 1	17
Right Channel in Geology 1	18
Left Channel in Geology 3	19
Mid Channel in Geology 3	20
Right Channel in Geology 3	21

Estimating recharge for each zone

Recharge for each zone has been calculated in an excel spread sheet keeping the recharge factors as variables which have been adjusted during calibration. The formula used to calculate recharge for each recharge zone has been tabulated in Table 4.8.

Infiltration Factor, Split Factor and Runoff Factor are interrelated and were considered as calibration parameters. Underestimation of one factor has been compensated

Table 4.8. Recharge estimation formula

PRE-DAM

Z11	IF11* FunctionA
Z10	IF10* (1-IF11)*FunctionA
Z12	IF12* SF1*(1-IF10)*(1-IF11)*FunctionA
Z13	IF13*{(1-SF1)*(1-IF10)*(1-IF11)*FunctionA+(Rock3+Rock4)*R2+ROF*Area8*R2}
Z15	IF15*SF2{(1-IF12)* SF1*(1-IF10)*(1-IF11)*FunctionA+ROF*Area2*0.5*R1}
Z19	IF19*[(1-IF15)*SF2{(1-IF12)*SF1*(1-FunctionA+ROF*Area2*0.5*R1)}+ROF*Area3*0.4*R-Sohar]
Z20	IF20*[(1-SF2)*{(1-IF12)*SF1*(1-IF10)*(1-IF11)*FunctionA+ROF*Area2*0.5*R1} +(Area20+Area3*0.5*ROF)*R-sohar]

POST-DAM

Z11	IF11* (FunctionA-DamInflow)
Z10	IF10* (DamInflow-DamOutflow)
Z12	IF12*DamOutflow
Z13	IF13*((Rock3+Rock4)*R2+ROF*Area8*R2)
Z15	IF15*{SF2*(1-IF12)*DamOutflow+ ROF*Area2*0.5*R1}
Z19	IF19*{(1-IF15)*SF2*(1-IF12)*DamOutflow+ ROF*Area3*0.4*R-Sohar}
Z20	IF20*[(1-SF2)*{(1-IF12)*SF1*(1-IF10)*(1-IF11)*FunctionA+ROF*Area1*0.3* R1}]

Z1	IF1*Area1*R1
Z2	IF2*Area2*R1
Z3	IF3*Area3*(R-sohar+R-mulainih)/2
Z4	IF4*Area4*R-sohar
Z5	IF5*Area5*(R-sohar+R-mulainih)/2
Z6	IF6*Area6*(R-sohar+R-mulainih)/2
Z7	IF7*Area7*(R1+R2+R-mulainih)/3
Z8	IF8*Area8*R2
Z9	No zone
Z14	IF14*{Rock4*ROF*R2+(Area14+0.3*Area7*ROF)*R-Mulainih}
Z16	IF16*(1-IF13)*{ (Rock3+Rock4)*R2+ROF*Area8*R2}
Z17	IF17*{(Area17+0.3*Area1*ROF)*(R1+R2+R-Mulainih)/3}
Z18	IF18*(1-IF14)*{Rock4*ROF*R2+(Area14+0.3*Area7*ROF)*R-Mulainih}
Z21	IF21*(Area3*0.3*ROF+Area21)*R-Sohar

Function A= (WG-Mulaina+Rock1*R5+Rock2*R2)

SF1=0.8, SF2=0.1, Where,

IF = Infiltration Factor

ROF= Runoff factor

Rock= Area of exposed bedrock contributing to surface runoff in the catchment

R2= Rainfall in zone 2

Area1= Area of recharge zone 1

SF= Split Factor

WG- Mulaina = Wadi guage at Mulaina

by overestimation of another. This compensation has been made by matching the target hydrographs. It should also be noted that, to avoid complicacy in recharge formula and reduce the number of factors, no separate factor has been introduced for Evaporation loss. Rather it has been considered in the Infiltration Factor. Therefore, the value of the factors used in the model should not be considered as actual estimate.

4.5.4. Processing well abstraction

Well abstraction is the most important component for this study. Most of the abstraction takes place in the downstream part of the catchment. According to National Well inventory database the study area contains 3667 operational abstraction wells to meet a yearly net demand of 26.87 Mm^3. This includes agricultural, household, livestock, municipal, industrial and commercial demand. Abstraction rate was provided in l/s for a number of wells but pumping hours were not available. Initially a gross estimate was made considering 8 hours pumping per day which resulted in more than 100 Mm^3/yr abstractions which by far overestimates the total abstraction given in the report. Yearly net water demand was available which was considered as yearly abstraction. The yearly abstraction was then distributed between summer and winter. There are 6 SDO wells in the catchment. Therefore, monthly abstraction rate has been used for these wells.

4.6. Model Calibration

Nature is a very complex system. Man could understand very little about this complex behaviour of nature. Due to the limitation of human knowledge, refinement of the conceptual model is required during the modeling process. This system of refinement of the conceptual model is termed as model calibration. It is a trial and error method where by overestimation of another. This compensation has been made by matching the target hydrographs. It should also be noted that, to avoid complicacy in recharge formula and reduce the number of factors, no separate factor has been introduced for Evaporation loss. Rather it has been considered in the Infiltration Factor. Therefore, the value of the factors used in the model should not be considered as actual estimate.

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4.6. Model Calibration

Nature is a very complex system. Man could understand very little about this complex behaviour of nature. Due to the limitation of human knowledge, refinement of the conceptual model is required during the modeling process. This system of refinement of the conceptual model is termed as model calibration. It is a trial and error method where the initial estimates of the model parameters are adjusted to produce a better match between simulated and observed conditions.

Calibration in groundwater modeling is done by comparing the model generated heads with measured water levels. Therefore, the first step of model calibration is to set targets. A calibration target is a point in space and time where one of the model dependent variables has been measured. Calibration targets provide a means of assessing calibration quality, because an error term, called a residual, is computed for each target location. A residual is computed as the field measurement minus the model-computed value. The range of errors helps to determine whether the quality of the calibration is adequate for the study purposes. In addition to the groundwater head comparison, concentration, draw down, or groundwater flow (called flux in the following discussion) can also be used as calibration targets. Targets may be steady-state or may have an associated time value (called transient targets). For the present study transient head targets have been used.

4.6.1. Areal calibration

Arial calibration is done to minimize the spatial difference between observed and model generated values. To get a satisfactory calibration result the targets should be spatially distributed. Accuracy of the areal calibration can be increased by increasing the number of targets. However, the frequency of targets can lead to a very complex model with lower performance. To compromise between accuracy and model performance more targets were selected in the area of interest i.e alluvial plane in the lower catchment. Most of the abstraction and seawater intrusion occurs there. Moreover, more observation wells are located in the lower catchment. Figure 4.1 shows the location of monitoring stations which have been used as targets for areal calibration.

Arial calibration has been done manually for the end stress period (December 1994). Matching the end stress period also reduces the difference in time series. In addition to hydraulic conductivity and specific yield, recharge, constant head inflow and through flow from the upper catchment have also been calibrated at this stage to give a reasonable estimate of the components.

Due to uneven distribution of water level measurement points over the whole catchment the WL contours will not be realistic. Therefore, time series calibration for the known measurement points was attempted.

4.6.2. Key bore hydrographs calibration

After reaching an acceptable spatial calibration limit for the end stress period the model has been further calibrated over the simulation period to match the key bore hydrographs. Recharge and specific yield are the most widely used calibration components at this stage. If the pattern matches with some sudden variation in heads specific yield is changed to fasten or slow down the head response.

Figure 4.9 presents a good example of the effect of specific yield. The model generated hydrograph has a similar pattern of the observed hydrograph, but, shows some spikes which indicate an under estimation of specific yield. Therefore, the specific yield of the zone where the borehole falls has been increased.

Recharge is adjusted if the pattern of hydrograph differs and recharge variation along the time scale is questioned. Figure 4.10 presents a good example of recharge calibration. The comparison of hydrographs shows that recharge has been underestimated before dam construction. Further trial was attempted with increased pre-dam recharge. Error in any other time varying component (e.g. well abstraction) is also adjusted during this part of calibration. Two examples of the hydrograph comparison are presented in Figures 4.11 and 4.12. All the calibrated hydrographs are included in Appendix-F.

4.6.3. Calibration statistics

Calibration statistics are computed by first calculating the error associated with each target and then calculating simple statistics on the error of targets. The error is called a residual and is computed by subtracting the model-computed value (head, drawdown, concentration, or flux) from the target value. Negative residuals indicate that the model is calculating the dependent value too high and a positive residual is where the model value is too low. The types of statistics computed include the following:

- Sum of squared residuals
- Residual mean
- Residual standard deviation
- Absolute residual mean
- Residual standard deviation divided by range in target value

The sum of squared residuals is computed by squaring all residuals and adding them together. This statistic is meaningless by itself but is useful to plot on sensitivity curves or when judging several different simulations. The sum of squared residuals is used by inverse models in the automated calibration process. The residual mean is computed by dividing the sum of residuals by the number of residuals. Because both positive and negative residuals are used in the calculation, this value should be close to zero for a good calibration. In other words, the positive and negative errors should balance each other.

The absolute residual mean, on the other hand, is calculated using the absolute value of the error (only positive values) and is a measure of the average error in the model. The residual standard deviation is a measure of the overall spread of residuals. It can be compared to the overall range in target value (e.g., head) as a further comparison. For head

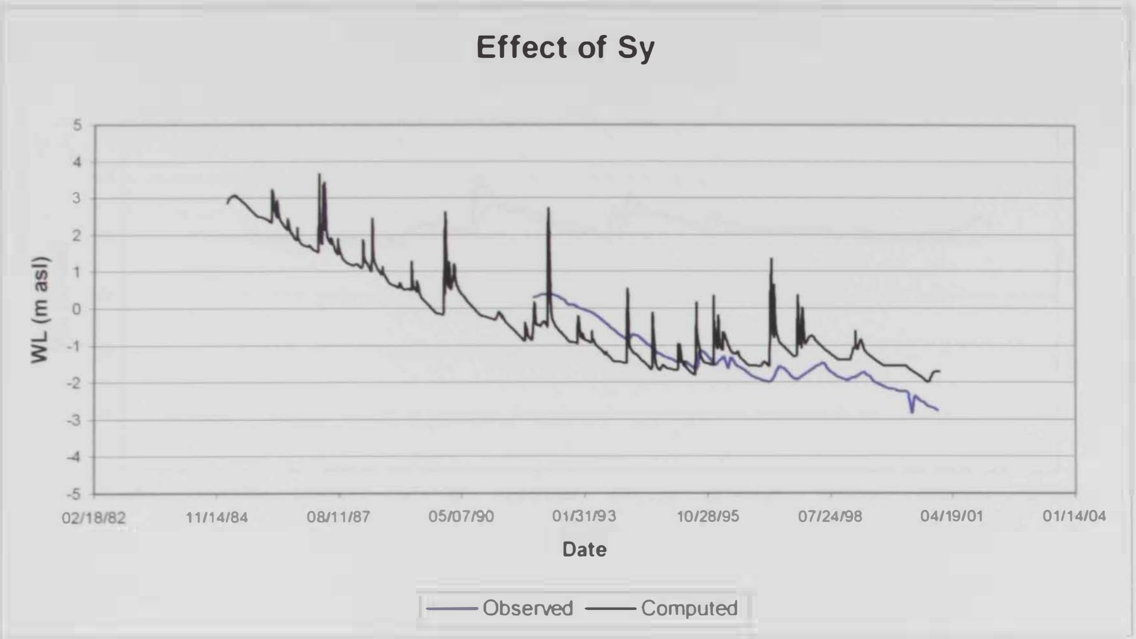

Figure 4.9. The effect of specific yield

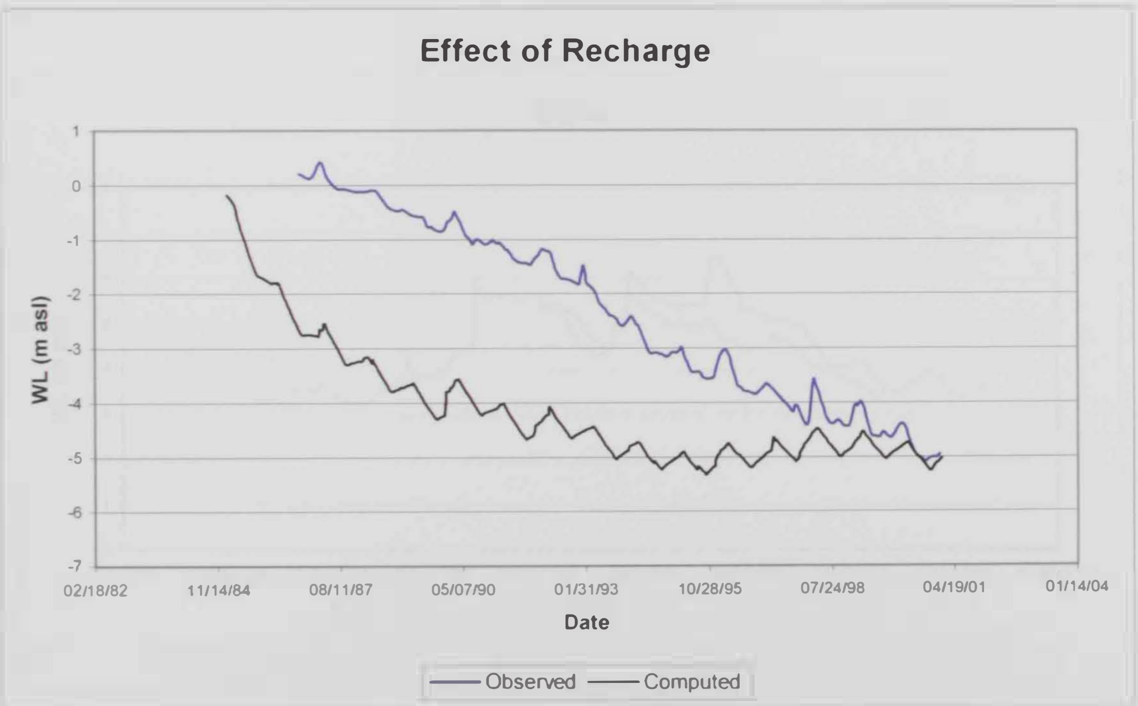

Figure 4.10. The effect of recharge

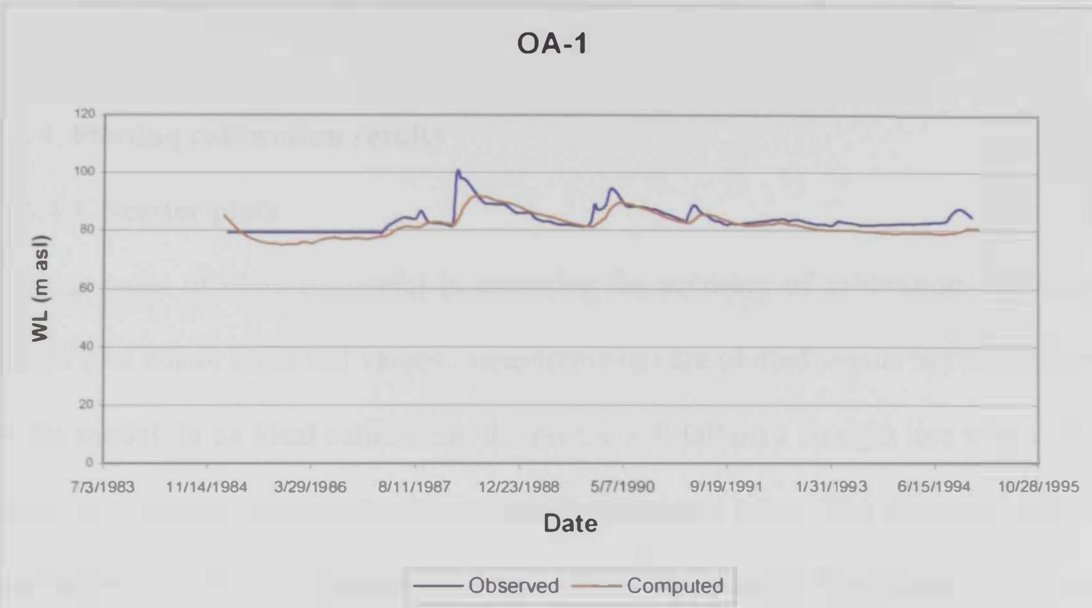

Figure 4.11. Observed and computed values of water level for well OA-1 between 1983 and 1995

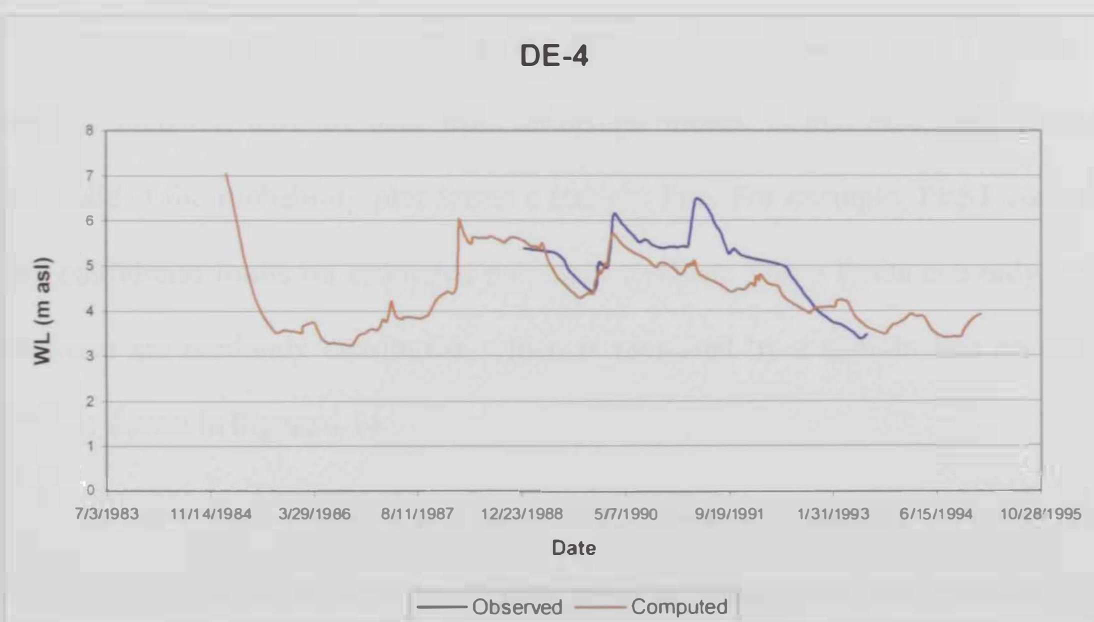

Figure 4.12. Observed and computed values of water level for well DE-4 between 1983 and 1995

targets, this value shows how the errors relate to the overall gradient across the model. Normally, this value should be less than 10 to 15 percent for a good calibration.

4.6.4. Plotting calibration results

4.6.4.1. Scatter plots

Various types of plots are useful in assessing the accuracy of calibration. The first is the scatter plot where observed values (measurements) are plotted versus the values computed by the model. In an ideal calibration, the points will fall on a straight line with a 45 degree slope; i.e., that the computed value equals the measured value. The degree of scatter about this theoretical line is a measure of overall calibration quality. The scatter plot of observed versus simulated head values for the calibrated model is shown Figure 4.13.

The scatter plot, Figure 4.13, shows a good calibration of the model as most of the points fall on the 45^0 line. Few deviated points are due to residuals errors during total simulation period of 3651 days.

Another type of scatter plot is the cumulative probability plot. This plot is only useful if statistical tests are used from an inverse model. In that case, these statistics are only valid if the probability plot forms a straight line. For example, PEST computes the 95% confidence limits on estimated parameters values. These limits can only be used if the errors are randomly distributed, which is indicated by a straight line on probability plots, as shown in Figure 4.14.

Another type of scatter plot is a cumulative sum of squared residuals plot. This shows whether just a few targets with large errors are biasing the sum of squares. This can be important if we intend to use the automatic sensitivity analysis or inverse models which rely on this statistic. The graph becomes skewed if only few target points affect the

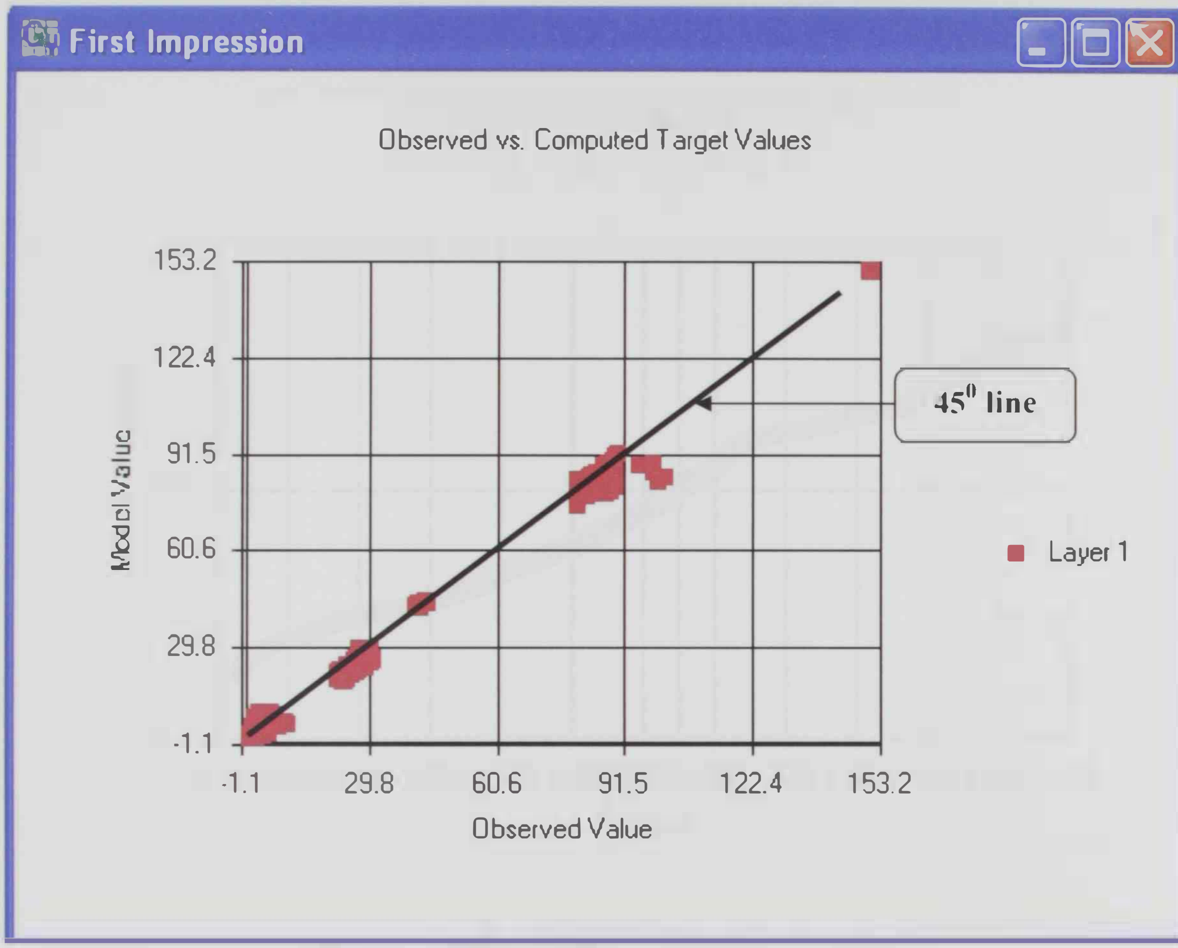

Figure 4.13. Scatter plot- observed verses computed target values

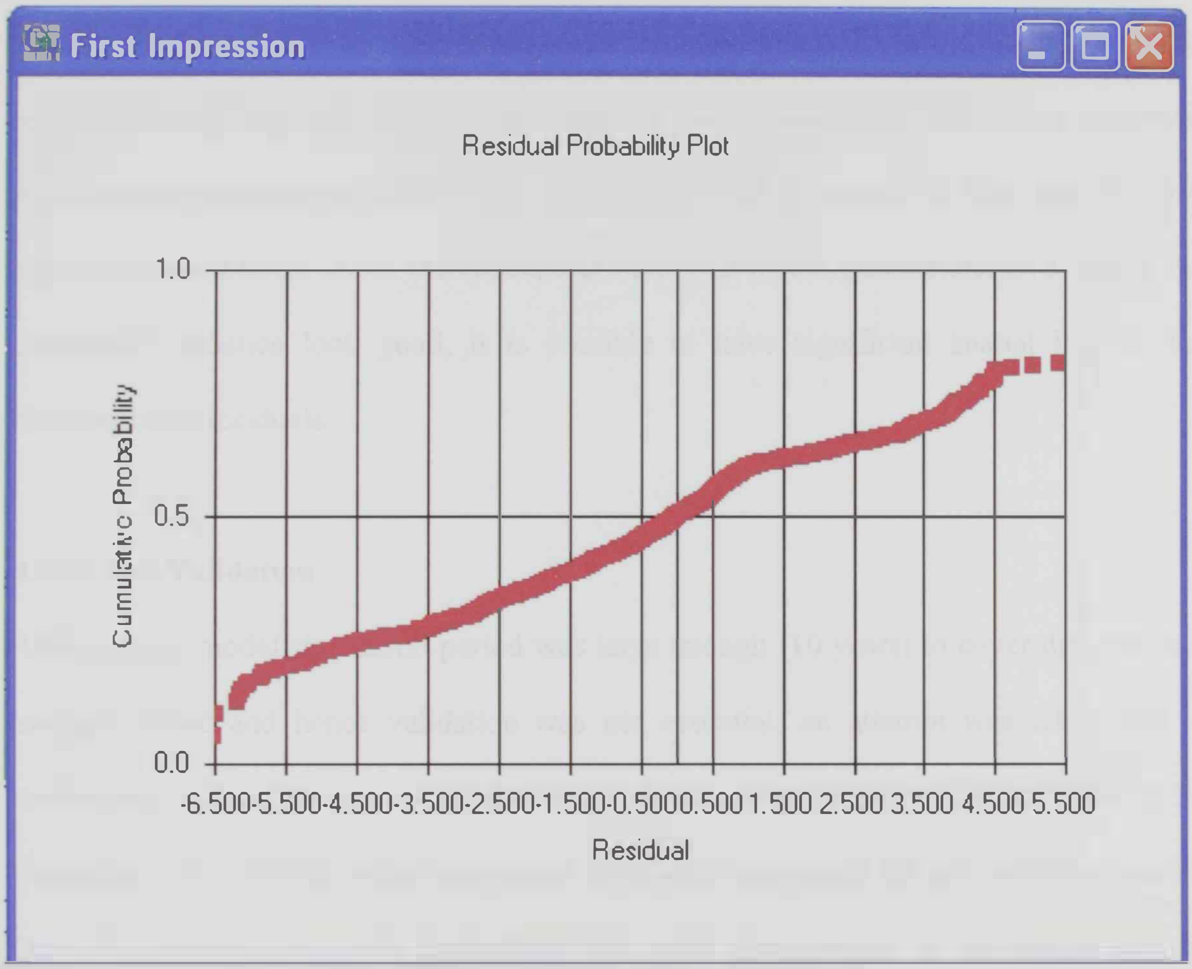

Figure 4.14. Scatter plot- cumulative probability

calibration result. In this case, one should investigate what targets these are and whether they might have data quality problems. Figure 4.15 shows plot from the calibrated model.

4.6.4.2. Posting residuals

Another type of plot that is useful in assessing calibration quality is a contour map of the model dependent variable (e.g., head) with residuals posted on the contours. These residual posting maps are useful in pointing out spatial bias in the distribution of errors. Areas where residuals are all too high or too low should be looked at. This indicates that something is incorrect about the conceptual model or model parameters. Even when the calibration statistics look good, it is possible to have significant spatial bias in the distribution of residuals.

4.7. Model Validation

Although the model simulation period was large enough (10 years) to cover dry, wet and average period and hence validation was not essential, an attempt was taken due to availability of data. The model validation period was selected from 1 January 1995 to 31 December 2002. All the model parameters were kept unchanged for the validation model. Only the recharge and well abstraction data were incorporated in the model for the specified period. The stress periods were also adjusted as per the validation period's wadi flow. The simulated heads from validation model, as expected, were also close to the measured head. Figures 4.16 and 4.17 present the comparison between observed and computed values between 1995 and 2002. Whole set of comparison hydrographs are plotted in Appendix G.

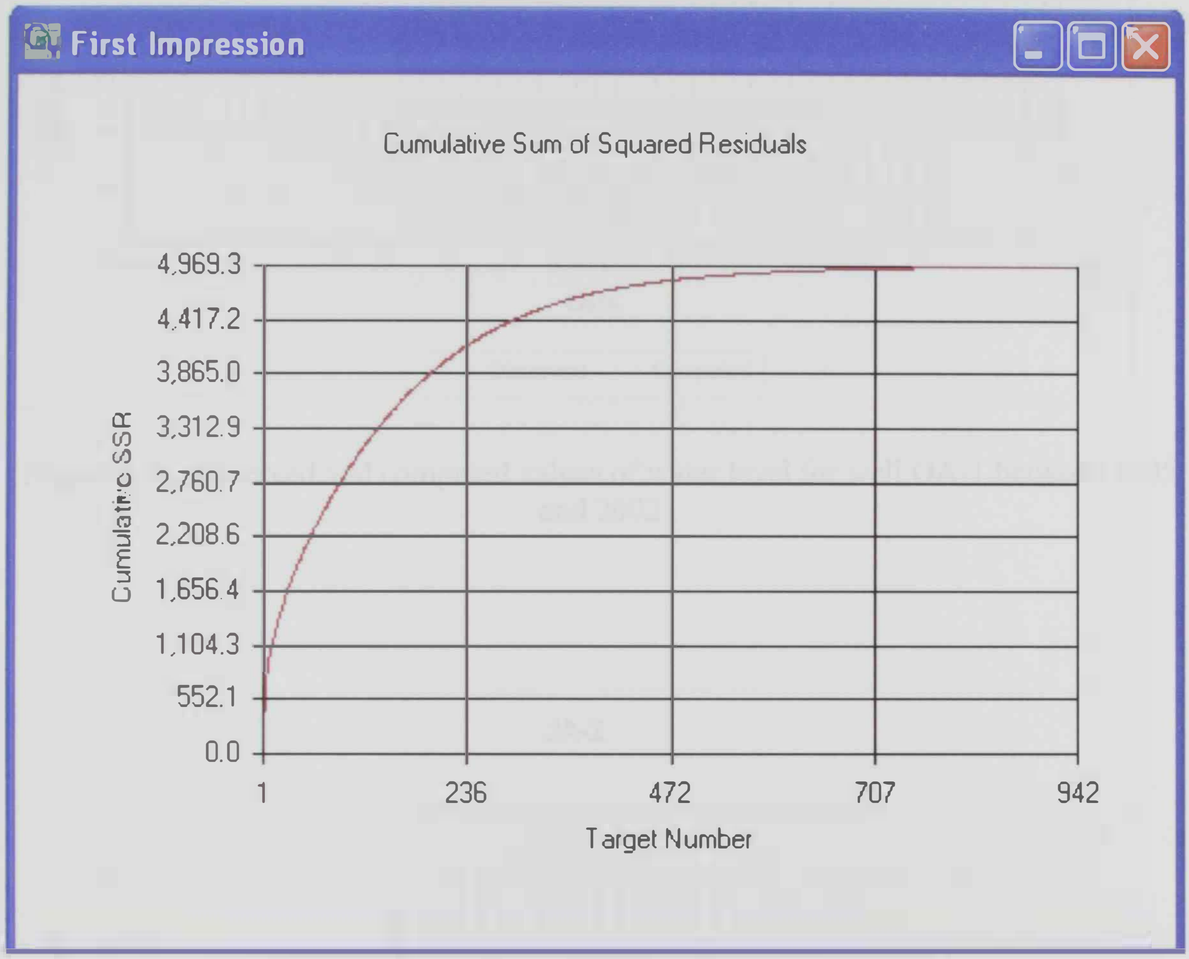

Figure 4.15. Scatter plot- cumulative verses residuals

Figure 4.16. Observed and computed values of water level for well OA-1 between 1995 and 2002

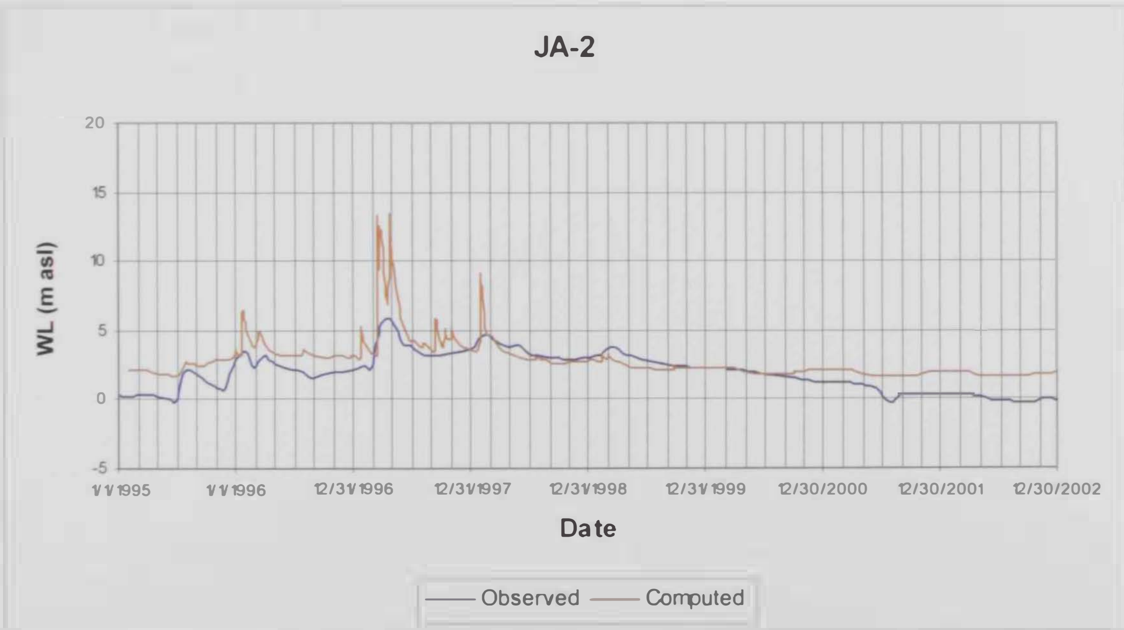

Figure 4.17. Observed and computed values of water level for well JA-2 between 1995 and 2002

4.8. Simulation of Future Scenarios

Although developing a transient model takes a lot of time and effort, in the end, if properly calibrated, it can predict future groundwater situation very easily. Good field data are essential when using a model for predictive purposes (Wang & Anderson, 1982). For the present study a prediction for 2020 has been simulated assuming no intervention. This scenario predicts the situation until 2020 if no protective measure is applied to stop the groundwater head decline. Following assumptions have been made in this scenario-

- Rainfall pattern will remain same
- No change in abstraction pattern will occur.
- Post dam infiltration pattern will be maintained for the entire simulation period

The following points were not considered in this scenario-

- No sea level rise has been considered
- No climate change has been considered

The resulted hydrographs are included in Appendix H. An example is shown in Figures 4.18 and 4.19.

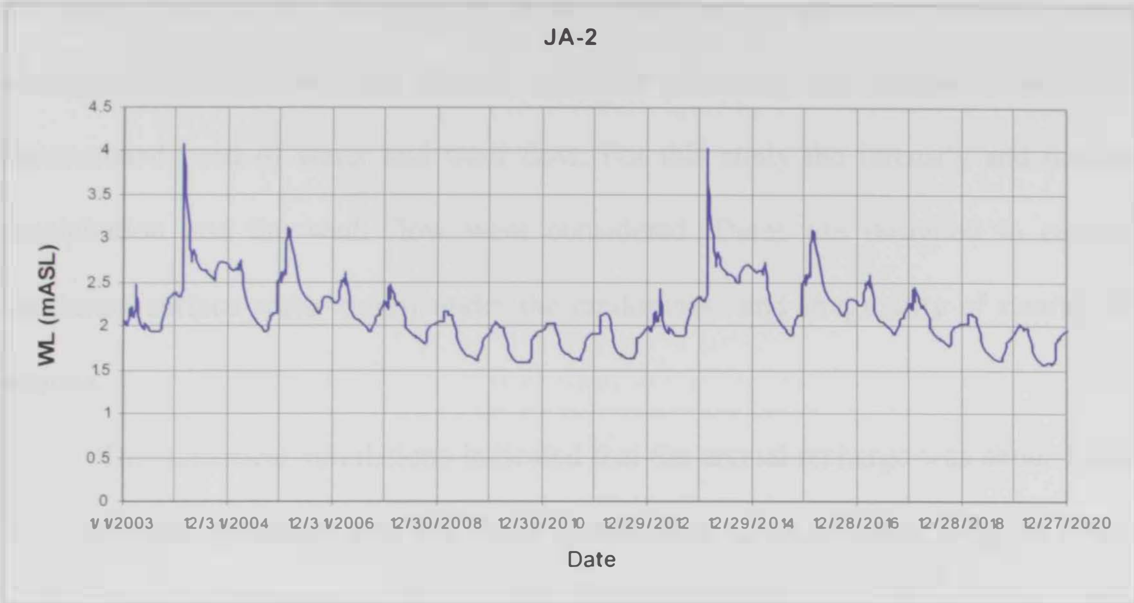

Figure 4.18. Predicted water level between 2003 and 2020 for well JA-2

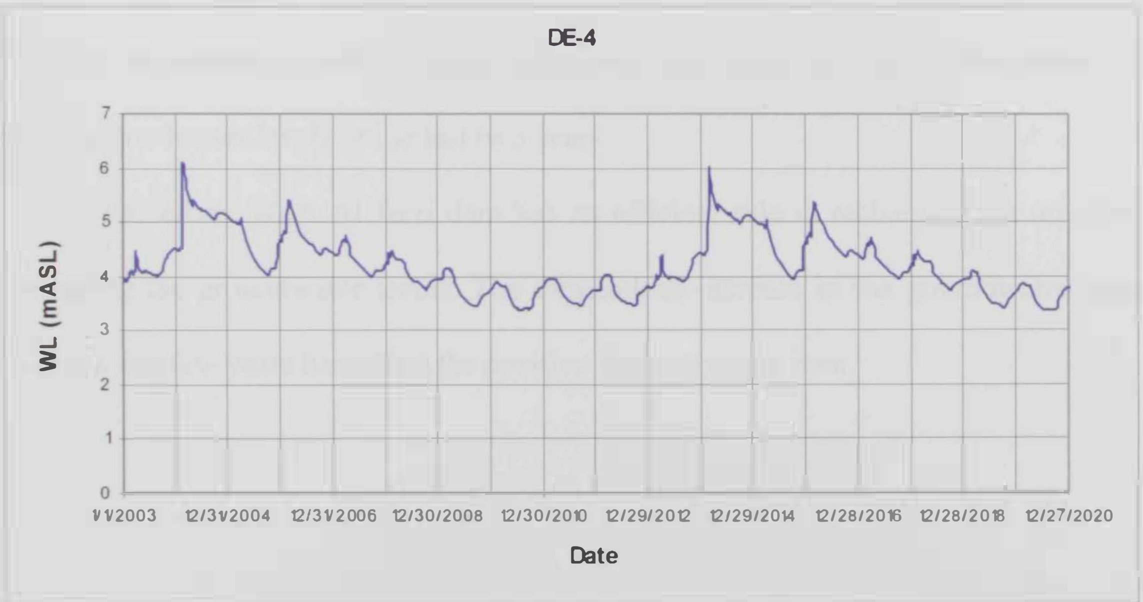

Figure 4.19. Predicted water level between 2003 and 2020 for well DE-4

4.9. Recharge Assessment

Artificial recharge of depleted aquifers is the prime target of construction of dams across the main Wadis in the Sultanate of Oman. Many factors affect the recharge including, among others, soil conditions, climatic conditions, intensity and duration of precipitation, accumulated head of water and wadi flow. For this study the intensity and duration of precipitation and the wadi flow were considered. Dams are designed to capture the maximum surface water runoff under the randomness and irregularity of rainfall in arid regions.

The numerical simulations indicated that the annual recharge was about 1,825,000 m^3 prior to the construction of the Wadi Al Jizzi dam (period between Jan 1985 and Aug 1989). After the construction of the dam (period between Sep 1989 and Dec 1994) the annual recharge is estimated at 2.492,000 m^3. It is therefore concluded that the dam has increased the annual recharge in Wadi Al-Jizzi by about 36 %. This can be clearly seen in the rise of groundwater levels after any flood event especially in the wells downstream of the dam. Nevertheless, over pumping along with the scarcity of rainfall has caused a drop in the groundwater levels in the last two years.

Therefore, Wadi Al-Jizzi dam has an efficient role in recharging the aquifers and increasing the groundwater levels. The tremendous increase in the groundwater pumping over the last few years has offset the positive impacts of the dam.

Chapter 5. Summary and Conclusions

5.1. Summary

Groundwater is a fundamental resource of water especially in areas characterized by arid and semi-arid conditions, where the temperature high and rainfall is infrequent, scattered and limited. Normally in arid and semi-arid climatic zones, towns and villages are developed close to the water sources, particularly beside wadi channels or wells. In the absence of sufficient surface water resources, the groundwater is regarded as the major source that is available for different uses. Due to the increase in population along with the enhanced living standards, new agricultural, industrial and commercial activities, groundwater abstraction has increased to satisfy the demands. This can reach unsustainable levels causing depletion in production and/or deterioration of the water quality which may render the water unsuitable for its intended use. Groundwater resources should, therefore, be managed in such a way to provide sustainable water supply for domestic, agriculture and industrial use.

The Sultanate of Oman lies in an arid region of the world with irregular and rare rainfall. There is very little availability of fresh water, the demand is predominantly met by the groundwater supplies. However, desalinated water in conjunction with groundwater is supplied to some of the major towns. Aflaj are also used to deliver water into the demand areas. Aflaj were introduced into Oman about a thousand years ago and were used to transport either groundwater or surface water. In Falaj system, water is tapped at the water table in the mountains and in wadis, and is led by man-made subterranean channels or by channels that skirt and cling to mountain sides to areas where water is used for irrigation and domestic purposes without any mechanical device. About 92 % of the groundwater in Sultanate of Oman is used for agricultural purposes.

In the Sultanate of Oman, most of the surface runoff flows to the sea. To benefit of this wasted surface runoff, many recharge dams were built across the main wadis in the interior and on the coastal plain starting in the mid 1980's. Eighteen recharge dams have been constructed and several others are planned. Artificial recharge is used mainly to minimize the current water deficit and reduce the seawater intrusion in coastal groundwater systems.

This study aimed at assessing the groundwater recharge from Wadi Al-Jizzi dam in the Sultanate of Oman. To that end, all previous studies and investigations related to Wadi Al-Jizzi were reviewed. The required information and data about geology, hydrology, hydrogeology and the historical records of groundwater levels, surface water flow and rainfall were also gathered from MMEWR to serve the purpose of this study.

Several maps were developed to present the boundary of Wadi Al-Jizzi catchment and the locations of the dam, monitoring wells, rain gauges and flow gauges along the wadi. Numerical simulation for the groundwater system in Wadi Al-Jizzi, for the period 1985 to 2020 was performed to assess the future groundwater levels changes under the present conditions of pumping and recharge.

A USGS finite difference groundwater flow model "MODFLOW" was employed to simulate droundwater flow and levels in Wadi Al-Jizzi aquifer system. The model was conceptualized with single layer representing the alluvial aquifer. The study domain has been selected from the end of the impermeable bedrock to the eastern coast line. The entire Western part of the catchment (upper catchment) is not included in the model domain as most of it is covered by impermeable rocks which is treated as no flow boundary. Recharge component includes the surface runoff from the upper catchemnt. The through flow from the upper catchment has been considered by constructing a general head boundary.

The model parameters have been calibrated until a satisfactory match between the observed and simulated groundwater levels in most of the observation wells has been achieved for the period 1985 – 1994. The model was then validated, without changing the calibrated parameters, for the period 1995 to 2002. Predictions are made for the groundwater levels for the period 2003 - 2020 assuming same groundwater pumping patterns and same climatic conditions.

5.2. Conclusions

This study aims to assess the effectiveness of Wadi Al-Jizzi dam in enhancing the recharge process in the catchment area of Wadi Al-Jizzi. Several conclusions are made based of the results of the study.

1. The total area of Wadi Al-Jizzi catchment is about 1154 km^2, the area of the upper catchment is 635 km^2 and the area of the lower catchment is 519 km^2.
2. Groundwater resources are generally overexploited leading to a considerable decline in groundwater levels. About 95% of the pumped groundwater is used for irrigation purposes. A remarkable decline in the groundwater level was observed in 2003. This was also associated with a deterioration of the groundwater quality especially near the coast.
3. The mean annual rainfall varies between 100 mm in the low-laying plain and 160 mm in the mountainous areas. Ten rainfall gauges are distributed in the catchment area of Wadi Al-Jizzi.
4. The feasibility study of the dam of Wadi Al-Jizzi anticipated that the dam would provide an annual recharge of about $3.5x10^6$ m^3 which can be used for agricultural development and stabilization of the groundwater condition in Sohar area. Another study estimated that a volume of about $8.4x10^6$ m^3 recharged the groundwater

system between 1989 and 1990. Since its construction in 1989 until 2003, the dam has provided a total volume of about 116.44 x 10^6 m^3.

5. MODFLOW was employed successfully to simulate the groundwater flow and levels in the aquifer of Wadi Al-Jizzi. A study area of 30km x 30km was considered in the simulation and was divided into 22500 regular cells.
6. The model was calibrated for the period 1985 – 1994. The ten year simulation time has been divided into 198 stress periods. Stress periods were chosen such that hydrological events can be considered constant throughout the stress period. The longest stress was taken as one month.
7. The model was validated for the period 1995 to 2002. A satisfactory fit between the computed and observed water heads in the selected observation wells that are mostly located near the coast was achieved. A good response to the wet and dry periods of recharge was observed.
8. The model predicted water level changes for selected monitoring wells located within the study area. These predicted hydrographs provide an indication of the magnitude of the change in water levels that can be expected to occur if the predicted recharge and extraction rates are implemented. The graphs indicate that water levels would fluctuate according to the expected wet and dry recharge periods with significant declines and more seawater intrusion in the dry periods. The system recovers in the wet years.
9. The effect of Wadi Al-Jizzi recharge dam is quite significant in the wells located just downstream of the dam. The dam has a minor effect on the wells located in the coastal area because of the intensive pumping for agricultural purposes.

10. Based on the results of the numerical simulation, the dam has increased the annual groundwater recharge by 36% as compared to the conditions prior to the construction of the dam.

5.3. Recommendations

Groundwater resources are over-exploited to meet the agricultural demands. Natural recharge is much less than the pumping leading to a continuous decline in the groundwater levels. This is also associated with a deterioration in the groundwater quality. Based on the results of this study, the following recommendations are made to sustain the groundwater resources.

1. Pumping of groundwater resources in Wadi Al-Jizzi area should be reduced as much as possible. Groundwater pumping should be controlled and monitored to ensure its sustainability.
2. Modern irrigation techniques including drip and sprinkler irrigation should be implemented to reduce water consumption for agricultural irrigation purposes.
3. A database including accurate information regarding the geological and hydrogeological setting of the aquifer and groundwater pumping and distribution should be established. This would allow for a better assessment of the groundwater resources in the region.
4. Study various scenarios for groundwater pumping and management using the developed model to identify the safe yield of the aquifer and ensure the sustainability of the groundwater resources in Wadi Al-Jizzi catchment. The proposed scenarios should take into account the political, economical and social impacts.

5. Conduct comprehensive field and numerical studies to identify different methods to enhance the recharge from dams in Oman.
6. The Water Resources National Master Plan should be updated and implemented. This master plan should account for dry and wet conditions.

Abbreviations

amsl	Above Mean Sea Level
DGIA	Directorate General for Irrigation Affairs
DGWRA	Directorate General Water Resources Assessment
DRMEWR	Directorate of Regional Municipality, Environment and Water Resources
EC	Electrical Conductivity
FW/SW	Freshwater/Seawater
GISS	Geographical Information System Section
JICA	Japan International Cooperation Agency
km	Kilometer
km^2	Square Kilometer
l/s	Liter Per Second
MRMEWR	Minister of Regional Municipalities, Environment and Water Resources
MNE	Ministry of National Economics
MOCI	Ministry of Commerce and Industry
MWR	Ministry of Water Resources
MWRRS	Ministry of Water Resources Recharge Section
NWI	National Well Inventory
mm	Millimeters
MCM	Million Cubic Meters
m^3	Cubic Meter
M	Meter
m^2/d	Square Meter Per Day
SDO	Sohar Development Office
TDS	Total Dissolved Solids
UAE	United Arab Emirates
WMA	Water Management Areas
WHO	World Health Organization
USGS	United States Geological Survey
%	Percent
yr	Year
E	Easting
N	Northing

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Appendix A
Distribution of operational and abounded wells

Distribution of operational and disused wells at Wadi Al-Jizzi catchment. (MRMEWR database)

Lower Catchment					**Upper Catchment**				
Dug Wells	Boreholes	Pits	Sealed	Total	Dug Wells	Boreholes	Pits	Sealed	Total
3941	232	1	15	**4189**	283	27	-	-	**310**

ZONE	SUB-ZONE	Well Status\ Number Of Wells					
		Backfilled	Disused	Exploration/ Observation	Operational	Under-Construction	Unknown
Zone 1 (Lower Catchment)	1	-	10	-	146	-	-
	2	8	4	-	179	-	-
	3	22	25	-	224	-	-
	4	16	11	-	76	-	-
	5	20	6	-	66	-	-
	6	1	7	-	103	-	-
	7	3	24	-	44	-	-
	8	10	37	-	241	-	-
	9	4	10	1	88	-	-
	10	1	30	-	222	-	-
	11	5	21	-	130	-	-
	12	11	12	-	62	1	-
	13	4	15	-	77	-	-
	14	13	21	-	104	-	-
	15	-	24	-	146	1	-
	16	7	6	-	89	-	-
	17	5	23	-	111	-	-
	18	7	22	-	109	-	-
	19	1	11	-	115	-	-
	20	-	9	-	160	-	-
	21	1	9	-	146	-	1
	22	-	19	-	368	-	-
	23	-	4	-	41	-	-
	24	-	10	-	77	-	-
	25	1	2	-	78	-	-
	26	-	5	-	59	-	-
	27	-	6	1	29	-	-
	28	-	-	5	7	-	-
	29	1	1	4	1	-	-
	Total	**142**	**384**	**11**	**3649**	**2**	**1**
Zone 2 (Upper Catchmen)	30	11	26	1	72	-	-
	31	1	33	1	109	-	-
	32	-	9	2	22	-	-
	Total	**12**	**68**	**4**	**226**	**-**	**-**

Appendix B
Rainfall data

Rainfall data (MRMEWR database)

Local Name	Site ID	Date	Rainfall(mm)	Rainy Days
AL JIZZI	DM580942AF	Dec-93	13.9	1
AL JIZZI	DM580942AF	Mar-94	10.4	2
AL JIZZI	DM580942AF	Aug-94	1.6	2
AL JIZZI	DM580942AF	Oct-94	12.8	1
AL JIZZI	DM580942AF	Feb-95	1.4	3
AL JIZZI	DM580942AF	Mar-95	11	5
AL JIZZI	DM580942AF	Jul-95	60.6	4
AL JIZZI	DM580942AF	Aug-95	0.6	1
AL JIZZI	DM580942AF	Oct-95	1	1
AL JIZZI	DM580942AF	Nov-95	2.8	1
AL JIZZI	DM580942AF	Dec-95	83.2	5
AL JIZZI	DM580942AF	Jan-96	51.8	8
AL JIZZI	DM580942AF	Feb-96	10.6	6
AL JIZZI	DM580942AF	Mar-96	34.8	6
AL JIZZI	DM580942AF	Apr-96	0.4	1
AL JIZZI	DM580942AF	May-96	0.2	1
AL JIZZI	DM580942AF	Jun-96	3.6	2
AL JIZZI	DM580942AF	Aug-96	0.2	1
AL JIZZI	DM580942AF	Dec-96	0.4	2
AL JIZZI	DM580942AF	Jan-97	23.2	4
AL JIZZI	DM580942AF	Mar-97	85.8	10
AL JIZZI	DM580942AF	Apr-97	35.2	6
AL JIZZI	DM580942AF	Oct-97	9	2
AL JIZZI	DM580942AF	Nov-97	41	9
AL JIZZI	DM580942AF	Dec-97	3.2	1
AL JIZZI	DM580942AF	Jan-98	72	10
AL JIZZI	DM580942AF	Feb-98	48.8	5
AL JIZZI	DM580942AF	Mar-98	3.6	3
AL JIZZI	DM580942AF	Apr-98	25.2	4
AL JIZZI	DM580942AF	Dec-98	9.7	3
AL JIZZI	DM580942AF	Jan-99	8.6	1
AL JIZZI	DM580942AF	Feb-99	4.4	2
AL JIZZI	DM580942AF	Mar-99	50.2	2
AL JIZZI	DM580942AF	Apr-99	3	1
AL JIZZI	DM580942AF	Oct-00	5.8	1
AL JIZZI	DM580942AF	Mar-02	20.2	3
AL JIZZI	DM580942AF	Apr-02	27	1
AL JIZZI	DM580942AF	May-02	2.2	3
L'AQAQ	DM476902AF	Dec-93	14.6	1
L'AQAQ	DM476902AF	Mar-94	6.3	2
L'AQAQ	DM476902AF	Jul-94	8	1
L'AQAQ	DM476902AF	Aug-94	2.2	1
L'AQAQ	DM476902AF	Oct-94	15.8	2
L'AQAQ	DM476902AF	Nov-94	20	3
L'AQAQ	DM476902AF	Feb-95	11.2	4
L'AQAQ	DM476902AF	Mar-95	42.6	8
L'AQAQ	DM476902AF	May-95	1	1
L'AQAQ	DM476902AF	Jun-95	0.4	1
L'AQAQ	DM476902AF	Jul-95	120.4	5

L'AQAQ	DM476902AF	Aug-95	0.4	1
L'AQAQ	DM476902AF	Oct-95	18.6	1
L'AQAQ	DM476902AF	Nov-95	2.2	2
L'AQAQ	DM476902AF	Dec-95	68.6	11
L'AQAQ	DM476902AF	Jan-96	60.4	10
L'AQAQ	DM476902AF	Feb-96	52.8	8
L'AQAQ	DM476902AF	Mar-96	62.4	6
L'AQAQ	DM476902AF	Apr-96	0.4	1
L'AQAQ	DM476902AF	Jun-96	10.8	2
L'AQAQ	DM476902AF	Dec-96	0.4	1
L'AQAQ	DM476902AF	Jan-97	20.2	4
L'AQAQ	DM476902AF	Mar-97	102	9
L'AQAQ	DM476902AF	Apr-97	79	5
L'AQAQ	DM476902AF	Jun-97	1.4	1
L'AQAQ	DM476902AF	Jul-97	1.6	1
L'AQAQ	DM476902AF	Oct-97	94.6	4
L'AQAQ	DM476902AF	Nov-97	88	9
L'AQAQ	DM476902AF	Dec-97	5.6	3
L'AQAQ	DM476902AF	Jan-98	45.8	10
L'AQAQ	DM476902AF	Feb-98	36.8	9
L'AQAQ	DM476902AF	Mar-98	3.4	1
L'AQAQ	DM476902AF	Apr-98	29.2	5
L'AQAQ	DM476902AF	Dec-98	2.8	5
L'AQAQ	DM476902AF	Jan-99	19	2
L'AQAQ	DM476902AF	Feb-99	7.6	5
L'AQAQ	DM476902AF	Mar-99	38.4	3
L'AQAQ	DM476902AF	Dec-99	5.2	2
L'AQAQ	DM476902AF	Apr-00	0.2	1
L'AQAQ	DM476902AF	Jul-00	3.8	2
L'AQAQ	DM476902AF	Mar-02	31	3
L'AQAQ	DM476902AF	Apr-02	16.8	1
L'AQAQ	DM476902AF	May-02	2.8	3
L'AQAQ	DM476902AF	Jun-02	1	1
L'AQAQ	DM476902AF	Jul-02	1.8	1
HAYL AL ADHAH	DM382737AF	Feb-82	140.5	5
HAYL AL ADHAH	DM382737AF	Mar-82	37.1	6
HAYL AL ADHAH	DM382737AF	May-82	7	1
HAYL AL ADHAH	DM382737AF	Oct-82	0.6	2
HAYL AL ADHAH	DM382737AF	Nov-82	13.4	1
HAYL AL ADHAH	DM382737AF	Feb-83	69.6	2
HAYL AL ADHAH	DM382737AF	Mar-83	23.3	6
HAYL AL ADHAH	DM382737AF	Nov-83	6	2
HAYL AL ADHAH	DM382737AF	Jul-84	10.5	2
HAYL AL ADHAH	DM382737AF	Sep-84	9.8	1
HAYL AL ADHAH	DM382737AF	Mar-85	1.2	1
HAYL AL ADHAH	DM382737AF	Apr-85	0.2	1
HAYL AL ADHAH	DM382737AF	Jan-86	26.6	1
HAYL AL ADHAH	DM382737AF	Feb-86	8.2	2
HAYL AL ADHAH	DM382737AF	Mar-86	9.4	1
HAYL AL ADHAH	DM382737AF	Oct-86	28	2
HAYL AL ADHAH	DM382737AF	Dec-86	5	1
HAYL AL ADHAH	DM382737AF	Feb-87	17.8	1

HAYL AL ADHAH	DM382737AF	Mar-87	71.5	7
HAYL AL ADHAH	DM382737AF	Apr-87	6.4	2
HAYL AL ADHAH	DM382737AF	Aug-87	7.5	1
HAYL AL ADHAH	DM382737AF	Sep-87	10	1
HAYL AL ADHAH	DM382737AF	Dec-87	3.5	1
HAYL AL ADHAH	DM382737AF	Feb-88	148.4	6
HAYL AL ADHAH	DM382737AF	Mar-88	4.6	1
HAYL AL ADHAH	DM382737AF	Apr-88	13.2	2
HAYL AL ADHAH	DM382737AF	Feb-89	16.5	1
HAYL AL ADHAH	DM382737AF	Mar-89	51.5	3
HAYL AL ADHAH	DM382737AF	Nov-89	26.3	2
HAYL AL ADHAH	DM382737AF	Dec-89	68.1	3
HAYL AL ADHAH	DM382737AF	Jan-90	25.8	6
HAYL AL ADHAH	DM382737AF	Feb-90	85	8
HAYL AL ADHAH	DM382737AF	Apr-90	10.5	3
HAYL AL ADHAH	DM382737AF	Jun-90	4.4	1
HAYL AL ADHAH	DM382737AF	Jul-90	4.5	1
HAYL AL ADHAH	DM382737AF	Feb-91	9.5	3
HAYL AL ADHAH	DM382737AF	Mar-91	36.5	4
HAYL AL ADHAH	DM382737AF	Dec-91	1.5	1
HAYL AL ADHAH	DM382737AF	Jan-92	16	4
HAYL AL ADHAH	DM382737AF	Feb-92	23.5	5
HAYL AL ADHAH	DM382737AF	Mar-92	2.9	2
HAYL AL ADHAH	DM382737AF	Apr-92	35	3
HAYL AL ADHAH	DM382737AF	Jul-92	3.5	1
HAYL AL ADHAH	DM382737AF	Oct-92	15	1
HAYL AL ADHAH	DM382737AF	Feb-93	33	2
HAYL AL ADHAH	DM382737AF	Apr-93	11.5	2
HAYL AL ADHAH	DM382737AF	Jan-98	39.5	8
HAYL AL ADHAH	DM382737AF	Feb-98	36	4
HAYL AL ADHAH	DM382737AF	Mar-98	2	1
HAYL AL ADHAH	DM382737AF	Apr-98	15	3
HAYL AL ADHAH	DM382737AF	May-98	2	1
HAYL AL ADHAH	DM382737AF	Dec-98	2	2
HAYL AL ADHAH	DM382737AF	Jan-99	10	2
HAYL AL ADHAH	DM382737AF	Feb-99	2	2
HAYL AL ADHAH	DM382737AF	Mar-99	31.5	4
HAYL AL ADHAH	DM382737AF	Jul-99	0.5	1
HAYL AL ADHAH	DM382737AF	Aug-99	4	1
HAYL AL ADHAH	DM382737AF	Sep-99	4	1
HAYL AL ADHAH	DM382737AF	Jan-00	2.5	1
HAYL AL ADHAH	DM382737AF	Jul-00	1.5	1
HAYL AL ADHAH	DM382737AF	Sep-00	5	1
HAYL AL ADHAH	DM382737AF	Oct-00	3	1
HAYL AL ADHAH	DM382737AF	Dec-00	2	1
HAYL AL ADHAH	DM382737AF	Jan-03	2	1
HAYL AL ADHAH	DM382737AF	Mar-03	12	1
HAYL AL ADHAH	DM382737AF	Apr-03	8.5	1
HAYL AL ADHAH	DM382737AF	May-03	3	1
HAYL AL ADHAH	DM382737AF	Jul-03	0.5	1
AL KHAN	DM383052AF	Feb-82	34.5	5
AL KHAN	DM383052AF	Mar-82	28	5

AL KHAN	DM383052AF	Oct-82	1.5	2
AL KHAN	DM383052AF	Nov-82	2.5	1
AL KHAN	DM383052AF	Jan-83	2.5	1
AL KHAN	DM383052AF	Sep-84	2.6	1
AL KHAN	DM383052AF	Dec-84	5.2	1
AL KHAN	DM383052AF	Mar-85	1.8	1
AL KHAN	DM383052AF	Apr-85	0.2	1
AL KHAN	DM383052AF	Jan-86	0.8	1
AL KHAN	DM383052AF	Feb-86	33.4	4
AL KHAN	DM383052AF	Mar-86	15.4	2
AL KHAN	DM383052AF	Apr-86	3	3
AL KHAN	DM383052AF	Jun-86	2	1
AL KHAN	DM383052AF	Jul-86	22.8	1
AL KHAN	DM383052AF	Aug-86	30	2
AL KHAN	DM383052AF	Sep-86	8	2
AL KHAN	DM383052AF	Oct-86	20	2
AL KHAN	DM383052AF	Feb-87	8.8	2
AL KHAN	DM383052AF	Mar-87	62.2	9
AL KHAN	DM383052AF	Apr-87	28	3
AL KHAN	DM383052AF	Jul-87	9.8	1
AL KHAN	DM383052AF	Oct-87	5.6	2
AL KHAN	DM383052AF	Dec-87	6	1
AL KHAN	DM383052AF	Feb-88	241.6	13
AL KHAN	DM383052AF	Apr-88	33.6	3
AL KHAN	DM383052AF	Jul-88	3.2	1
AL KHAN	DM383052AF	Aug-88	4.2	1
AL KHAN	DM383052AF	Sep-88	0.6	1
AL KHAN	DM383052AF	Dec-88	1.8	2
AL KHAN	DM383052AF	Feb-89	19.8	3
AL KHAN	DM383052AF	Mar-89	36.6	4
AL KHAN	DM383052AF	Apr-89	13.8	4
AL KHAN	DM383052AF	Jul-89	0.4	1
AL KHAN	DM383052AF	Nov-89	5.6	2
AL KHAN	DM383052AF	Dec-89	77	5
AL KHAN	DM383052AF	Jan-90	23	4
AL KHAN	DM383052AF	Feb-90	104.2	8
AL KHAN	DM383052AF	Apr-90	6.2	3
AL KHAN	DM383052AF	Jun-90	1.6	2
AL KHAN	DM383052AF	Jul-90	3.4	2
AL KHAN	DM383052AF	Sep-90	8.8	1
AL KHAN	DM383052AF	Jan-91	0.2	1
AL KHAN	DM383052AF	Feb-91	17.6	4
AL KHAN	DM383052AF	Mar-91	42.6	2
AL KHAN	DM383052AF	Aug-91	3.4	1
AL KHAN	DM383052AF	Dec-91	5.2	5
AL KHAN	DM383052AF	Jan-92	20.2	8
AL KHAN	DM383052AF	Feb-92	25.2	3
AL KHAN	DM383052AF	Mar-92	5.8	4
AL KHAN	DM383052AF	Apr-92	53	3
AL KHAN	DM383052AF	Jul-92	3.8	1
AL KHAN	DM383052AF	Aug-92	0.2	1
AL KHAN	DM383052AF	Dec-92	3	1

AL KHAN	DM383052AF	Jan-93	8.8	2
AL KHAN	DM383052AF	Feb-93	12.2	3
AL KHAN	DM383052AF	Mar-93	1.2	2
AL KHAN	DM383052AF	Apr-93	4.4	2
AL KHAN	DM383052AF	Jul-93	2.8	1
AL KHAN	DM383052AF	Aug-93	3	1
AL KHAN	DM383052AF	Nov-93	0.6	2
AL KHAN	DM383052AF	Jan-94	9.6	3
AL KHAN	DM383052AF	Mar-94	9.8	3
AL KHAN	DM383052AF	Jul-94	15	1
AL KHAN	DM383052AF	Sep-94	6.4	1
AL KHAN	DM383052AF	Oct-94	20.6	4
AL KHAN	DM383052AF	Dec-94	0.2	1
AL KHAN	DM383052AF	Feb-95	6.2	4
AL KHAN	DM383052AF	Mar-95	8.8	7
AL KHAN	DM383052AF	Apr-95	0.8	1
AL KHAN	DM383052AF	May-95	0.4	1
AL KHAN	DM383052AF	Jul-95	157	6
AL KHAN	DM383052AF	Aug-95	14.6	1
AL KHAN	DM383052AF	Nov-95	11	2
AL KHAN	DM383052AF	Dec-95	20.8	8
AL KHAN	DM383052AF	Jan-96	47.2	9
AL KHAN	DM383052AF	Feb-96	5.8	5
AL KHAN	DM383052AF	Mar-96	69.2	4
AL KHAN	DM383052AF	Apr-96	0.4	1
AL KHAN	DM383052AF	Jun-96	6.4	2
AL KHAN	DM383052AF	Jul-96	11.6	3
AL KHAN	DM383052AF	Aug-96	13	2
AL KHAN	DM383052AF	Dec-96	4.8	2
AL KHAN	DM383052AF	Jan-97	16	4
AL KHAN	DM383052AF	Mar-97	71.8	6
AL KHAN	DM383052AF	Apr-97	58.4	3
AL KHAN	DM383052AF	Jun-97	0.6	2
AL KHAN	DM383052AF	Jul-97	3.6	1
AL KHAN	DM383052AF	Aug-97	11.4	1
AL KHAN	DM383052AF	Oct-97	29	5
AL KHAN	DM383052AF	Nov-97	31.4	4
AL KHAN	DM383052AF	Jan-98	16.8	4
AL KHAN	DM383052AF	Feb-98	41.8	6
AL KHAN	DM383052AF	Apr-98	18.6	3
AL KHAN	DM383052AF	Jul-98	32.8	2
AL KHAN	DM383052AF	Dec-98	2.8	2
AL KHAN	DM383052AF	Jan-99	2.6	2
AL KHAN	DM383052AF	Feb-99	18.4	3
AL KHAN	DM383052AF	Mar-99	44	5
AL KHAN	DM383052AF	Sep-99	21.8	2
AL KHAN	DM383052AF	Nov-99	0.6	1
AL KHAN	DM383052AF	Apr-00	1.6	1
AL KHAN	DM383052AF	Jul-00	5	3
AL KHAN	DM383052AF	Sep-00	2.6	2
AL KHAN	DM383052AF	Oct-00	11.4	3
AL KHAN	DM383052AF	Dec-00	4.2	1

AL KHAN	DM383052AF	Jan-01	0.6	1
AL KHAN	DM383052AF	Mar-02	21	3
AL KHAN	DM383052AF	Apr-02	7	1
AL KHAN	DM383052AF	May-02	10.2	1
AL KHAN	DM383052AF	Jul-02	12.4	2
AL KHAN	DM383052AF	Sep-02	2.8	1
AL FAR FAR	DM374569AF	Jan-74	4.6	2
AL FAR FAR	DM374569AF	Feb-74	50.4	2
AL FAR FAR	DM374569AF	Mar-74	5.3	1
AL FAR FAR	DM374569AF	Apr-74	2	1
AL FAR FAR	DM374569AF	Aug-74	6.4	1
AL FAR FAR	DM374569AF	Oct-74	13.9	1
AL FAR FAR	DM374569AF	Jan-75	6.2	1
AL FAR FAR	DM374569AF	Feb-75	84.5	4
AL FAR FAR	DM374569AF	May-75	4	1
AL FAR FAR	DM374569AF	Aug-75	25.6	2
AL FAR FAR	DM374569AF	Jan-76	26.1	2
AL FAR FAR	DM374569AF	Feb-76	126	4
AL FAR FAR	DM374569AF	Mar-76	97	5
AL FAR FAR	DM374569AF	Apr-76	85	3
AL FAR FAR	DM374569AF	Jul-76	3	1
AL FAR FAR	DM374569AF	Aug-76	62	2
AL FAR FAR	DM374569AF	Nov-76	12	1
AL FAR FAR	DM374569AF	Dec-76	1	1
AL FAR FAR	DM374569AF	Jan-77	27.2	3
AL FAR FAR	DM374569AF	Feb-77	33.7	2
AL FAR FAR	DM374569AF	Apr-77	67	1
AL FAR FAR	DM374569AF	May-77	47.7	4
AL FAR FAR	DM374569AF	Jun-77	33.2	1
AL FAR FAR	DM374569AF	Nov-77	13.7	1
AL FAR FAR	DM374569AF	Feb-78	54.1	2
AL FAR FAR	DM374569AF	Mar-78	3	1
AL FAR FAR	DM374569AF	Apr-78	6	1
AL FAR FAR	DM374569AF	Jun-78	5	1
AL FAR FAR	DM374569AF	Jul-78	12	2
AL FAR FAR	DM374569AF	Aug-78	73	3
AL FAR FAR	DM374569AF	Jan-79	18	2
AL FAR FAR	DM374569AF	Mar-79	3	1
AL FAR FAR	DM374569AF	Apr-79	12.7	1
AL FAR FAR	DM374569AF	Nov-79	22.4	3
AL FAR FAR	DM374569AF	Dec-79	21	3
AL FAR FAR	DM374569AF	Jan-80	4	1
AL FAR FAR	DM374569AF	Feb-80	18.8	2
AL FAR FAR	DM374569AF	Mar-80	34	2
AL FAR FAR	DM374569AF	May-80	5	1
AL FAR FAR	DM374569AF	Jul-80	17	2
AL FAR FAR	DM374569AF	Dec-80	8	1
AL FAR FAR	DM374569AF	Jan-81	5.3	1
AL FAR FAR	DM374569AF	Apr-81	22	1
AL FAR FAR	DM374569AF	May-81	30	1
AL FAR FAR	DM374569AF	Jul-81	9	1
AL FAR FAR	DM374569AF	Aug-81	5.7	1

AL KHAN	DM383052AF	Jan-01	0.6	1
AL KHAN	DM383052AF	Mar-02	21	3
AL KHAN	DM383052AF	Apr-02	7	1
AL KHAN	DM383052AF	May-02	10.2	1
AL KHAN	DM383052AF	Jul-02	12.4	2
AL KHAN	DM383052AF	Sep-02	2.8	1
AL FAR FAR	DM374569AF	Jan-74	4.6	2
AL FAR FAR	DM374569AF	Feb-74	50.4	2
AL FAR FAR	DM374569AF	Mar-74	5.3	1
AL FAR FAR	DM374569AF	Apr-74	2	1
AL FAR FAR	DM374569AF	Aug-74	6.4	1
AL FAR FAR	DM374569AF	Oct-74	13.9	1
AL FAR FAR	DM374569AF	Jan-75	6.2	1
AL FAR FAR	DM374569AF	Feb-75	84.5	4
AL FAR FAR	DM374569AF	May-75	4	1
AL FAR FAR	DM374569AF	Aug-75	25.6	2
AL FAR FAR	DM374569AF	Jan-76	26.1	2
AL FAR FAR	DM374569AF	Feb-76	126	4
AL FAR FAR	DM374569AF	Mar-76	97	5
AL FAR FAR	DM374569AF	Apr-76	85	3
AL FAR FAR	DM374569AF	Jul-76	3	1
AL FAR FAR	DM374569AF	Aug-76	62	2
AL FAR FAR	DM374569AF	Nov-76	12	1
AL FAR FAR	DM374569AF	Dec-76	1	1
AL FAR FAR	DM374569AF	Jan-77	27.2	3
AL FAR FAR	DM374569AF	Feb-77	33.7	2
AL FAR FAR	DM374569AF	Apr-77	67	1
AL FAR FAR	DM374569AF	May-77	47.7	4
AL FAR FAR	DM374569AF	Jun-77	33.2	1
AL FAR FAR	DM374569AF	Nov-77	13.7	1
AL FAR FAR	DM374569AF	Feb-78	54.1	2
AL FAR FAR	DM374569AF	Mar-78	3	1
AL FAR FAR	DM374569AF	Apr-78	6	1
AL FAR FAR	DM374569AF	Jun-78	5	1
AL FAR FAR	DM374569AF	Jul-78	12	2
AL FAR FAR	DM374569AF	Aug-78	73	3
AL FAR FAR	DM374569AF	Jan-79	18	2
AL FAR FAR	DM374569AF	Mar-79	3	1
AL FAR FAR	DM374569AF	Apr-79	12.7	1
AL FAR FAR	DM374569AF	Nov-79	22.4	3
AL FAR FAR	DM374569AF	Dec-79	21	3
AL FAR FAR	DM374569AF	Jan-80	4	1
AL FAR FAR	DM374569AF	Feb-80	18.8	2
AL FAR FAR	DM374569AF	Mar-80	34	2
AL FAR FAR	DM374569AF	May-80	5	1
AL FAR FAR	DM374569AF	Jul-80	17	2
AL FAR FAR	DM374569AF	Dec-80	8	1
AL FAR FAR	DM374569AF	Jan-81	5.3	1
AL FAR FAR	DM374569AF	Apr-81	22	1
AL FAR FAR	DM374569AF	May-81	30	1
AL FAR FAR	DM374569AF	Jul-81	9	1
AL FAR FAR	DM374569AF	Aug-81	5.7	1

AL FAR FAR	DM374569AF	Oct-81	34	1
AL FAR FAR	DM374569AF	Feb-82	155	8
AL FAR FAR	DM374569AF	Mar-82	34.4	4
AL FAR FAR	DM374569AF	Nov-82	6.7	1
AL FAR FAR	DM374569AF	Jan-83	4	1
AL FAR FAR	DM374569AF	Feb-83	25	3
AL FAR FAR	DM374569AF	Mar-83	30	3
AL FAR FAR	DM374569AF	Apr-83	33	2
AL FAR FAR	DM374569AF	Aug-83	41	1
AL FAR FAR	DM374569AF	Sep-84	3	1
AL FAR FAR	DM374569AF	Feb-86	35.7	3
AL FAR FAR	DM374569AF	Mar-86	8	1
AL FAR FAR	DM374569AF	Jun-86	10	1
AL FAR FAR	DM374569AF	Sep-86	9	2
AL FAR FAR	DM374569AF	Oct-86	12	1
AL FAR FAR	DM374569AF	Dec-86	8	1
AL FAR FAR	DM374569AF	Feb-87	14	1
AL FAR FAR	DM374569AF	Mar-87	60.7	5
AL FAR FAR	DM374569AF	Apr-87	32	1
AL FAR FAR	DM374569AF	Feb-88	155.3	6
AL FAR FAR	DM374569AF	Apr-88	32	3
AL FAR FAR	DM374569AF	Jul-88	8	1
AL FAR FAR	DM374569AF	Aug-88	14.8	1
AL FAR FAR	DM374569AF	Feb-89	15	1
AL FAR FAR	DM374569AF	Mar-89	22	2
AL FAR FAR	DM374569AF	Apr-89	37	3
AL FAR FAR	DM374569AF	Dec-89	79.3	3
AL FAR FAR	DM374569AF	Jan-90	34.7	2
AL FAR FAR	DM374569AF	Feb-90	110	6
AL FAR FAR	DM374569AF	Jun-90	9.4	1
AL FAR FAR	DM374569AF	Sep-90	24	2
AL FAR FAR	DM374569AF	Feb-91	12	2
AL FAR FAR	DM374569AF	Mar-91	55	5
AL FAR FAR	DM374569AF	Nov-91	66.5	2
AL FAR FAR	DM374569AF	Jan-92	14	2
AL FAR FAR	DM374569AF	Feb-92	24.4	4
AL FAR FAR	DM374569AF	Apr-92	55	2
AL FAR FAR	DM374569AF	Jan-93	10.8	1
AL FAR FAR	DM374569AF	Feb-93	38.7	2
AL FAR FAR	DM374569AF	Apr-93	9.4	1
AL FAR FAR	DM374569AF	Jan-94	5	1
AL FAR FAR	DM374569AF	Jul-94	31	1
AL FAR FAR	DM374569AF	Aug-94	7	1
AL FAR FAR	DM374569AF	Oct-94	29	2
AL FAR FAR	DM374569AF	Mar-95	30	2
AL FAR FAR	DM374569AF	Jul-95	121	3
AL FAR FAR	DM374569AF	Aug-95	9.6	1
AL FAR FAR	DM374569AF	Dec-95	34.3	3
AL FAR FAR	DM374569AF	Jan-96	20	4
AL FAR FAR	DM374569AF	Feb-96	5	1
AL FAR FAR	DM374569AF	Mar-96	169	3
AL FAR FAR	DM374569AF	Jun-96	3	1

AL FAR FAR	DM374569AF	Jul-96	4	1
AL FAR FAR	DM374569AF	Sep-96	4.1	1
AL FAR FAR	DM374569AF	Jan-97	98	3
AL FAR FAR	DM374569AF	Mar-97	122	7
AL FAR FAR	DM374569AF	Apr-97	49	2
AL FAR FAR	DM374569AF	Aug-97	14	1
AL FAR FAR	DM374569AF	Oct-97	19	2
AL FAR FAR	DM374569AF	Nov-97	3	1
AL FAR FAR	DM374569AF	Jan-98	36	3
AL FAR FAR	DM374569AF	Feb-98	33	3
AL FAR FAR	DM374569AF	Mar-02	36	3

Appendix C
Groundwater levels

Groundwater levels data(MRMEWR database)

Local ID	Mon Date	WL mASL	Local ID	Mon Date	WL mASL	Local ID	Mon Date	WL mASL
MS-2	Dec-81	240.99	JA-05	May-01	4.67	NJ-1	May-97	0.44
MS-2	Jan-82	241.04	JA-05	Jun-01	4.40	NJ-1	Jan-99	0.23
MS-2	Feb-82	244.33	JA-05	Aug-01	4.00	NJ-1	Feb-99	0.22
MS-2	Apr-82	244.16	JA-05	Sep-01	3.74	NJ-1	Mar-99	0.27
MS-2	May-82	243.1	JA-05	Oct-01	3.57	NJ-1	Apr-99	0.25
MS-2	May-82	242.23	JA-05	Nov-01	3.41	NJ-1	May-99	0.19
MS-2	Jun-82	241.57	JA-05	Dec-01	3.29	NJ-1	Jun-99	0.28
MS-2	Jul-82	242.29	JA-05	Jan-02	3.21	NJ-1	Jul-99	0.24
MS-2	Aug-82	241.14	JA-05	Feb-02	3.10	NJ-1	Aug-99	-0.03
MS-2	Sep-82	240.74	JA-05	Mar-02	2.96	NJ-1	Sep-99	0.11
MS-2	Oct-82	240.91	JA-05	Apr-02	2.88	NJ-1	Oct-99	-0.17
MS-2	Nov-82	240.78	JA-05	May-02	2.70	NJ-1	Nov-99	0.03
MS-2	Jan-83	240.55	JA-05	Jun-02	2.58	NJ-1	Dec-99	-0.12
MS-2	Feb-83	240.69	JA-05	Jul-02	2.49	NJ-1	Feb-00	0.1
MS-2	Mar-83	241.04	JA-05	Aug-02	2.38	NJ-1	Mar-00	-0.12
MS-2	Apr-83	244.1	JA-05	Sep-02	2.23	NJ-1	Apr-00	-1.93
MS-2	May-83	242.38	JA-05	Oct-02	2.16	NJ-1	May-00	0.1
MS-2	Jun-83	241.46	JA-05	Nov-02	2.06	NJ-1	Jan-01	-0.3
MS-2	Jul-83	240.6	JA-05	Dec-02	2.06	NJ-1	Feb-01	-0.11
MS-2	Sep-83	239.94	JA-05	Jan-03	2.05	NJ-1	Mar-01	0.06
MS-2	Nov-83	239.46	JA-05	Feb-03	2.05	NJ-1	Apr-01	-0.17
MS-2	Dec-83	237.89	JA-05	Mar-03	2.02	NJ-1	May-01	-0.28
MS-2	Feb-84	236.66	JA-05	Apr-03	1.97	NJ-1	Jun-01	-0.24
MS-2	Apr-84	236.41	JA-05	May-03	1.95	NJ-1	Aug-01	-0.3
MS-2	May-84	236.14	JA-05	Jun-03	-4.96	NJ-1	Sep-01	-0.3
MS-2	Jul-84	235.88	JA-06	Apr-82	60.64	NJ-1	Oct-01	-0.3
MS-2	Sep-84	233.68	JA-06	May-82	60.53	NJ-1	Nov-01	-0.28
MS-2	Oct-84	232.9	JA-06	May-82	60.53	NJ-1	Dec-01	-0.43
MS-2	Nov-84	232.26	JA-06	Jun-82	60.49	NJ-1	Jan-02	-0.37
MS-2	Dec-84	231.67	JA-06	Jul-82	60.47	NJ-1	Feb-02	-0.35
MS-2	Jan-85	231.67	JA-06	Aug-82	60.47	NJ-1	Mar-02	-0.37
MS-2	Feb-85	230.3	JA-06	Sep-82	60.45	NJ-1	Apr-02	-0.39
MS-2	Mar-85	229.62	JA-06	Oct-82	60.43	NJ-1	May-02	-0.27
MS-2	Apr-85	229.08	JA-06	Nov-82	60.46	NJ-1	Jun-02	-0.52
MS-2	May-85	228.6	JA-06	Jan-83	60.44	NJ-1	Jul-02	-0.59
MS-2	Jun-85	228.18	JA-06	Feb-83	60.41	NJ-1	Aug-02	-0.39
MS-2	Jul-85	227.8	JA-06	Mar-83	60.4	NJ-1	Sep-02	-0.39
MS-2	Aug-85	227.45	JA-06	Apr-83	60.41	NJ-1	Oct-02	-0.38
MS-2	Sep-85	227.07	JA-06	May-83	60.38	NJ-1	Nov-02	-0.49
MS-2	Oct-85	226.72	JA-06	Jun-83	60.36	NJ-1	Dec-02	-0.97
MS-2	Nov-85	227.25	JA-06	Jul-83	60.34	NJ-1	Feb-03	-0.44
MS-2	Dec-85	225.91	JA-06	Sep-83	60.32	NJ-1	Mar-03	-0.45
MS-2	Jan-86	225.46	JA-06	Nov-83	60.28	NJ-1	Apr-03	-0.31
MS-2	Feb-86	224.98	JA-06	Jan-84	60.26	NJ-1	May-03	-0.4
MS-2	Mar-86	224.82	JA-06	Feb-84	60.24	NJ-1	Jun-03	-0.3
MS-2	Apr-86	224.41	JA-06	Apr-84	60.21	NJ-2	Nov-89	0.06
MS-2	May-86	223.97	JA-06	May-84	60.16	NJ-2	Dec-89	0.25
MS-2	Jun-86	223.42	JA-06	Jul-84	60.15	NJ-2	Jan-90	0.09
MS-2	Jul-86	223.02	JA-06	Sep-84	60.11	NJ-2	Feb-90	0.22

MS-2	Aug-86	222.99	JA-06	Oct-84	60.06	NJ-2	Feb-90	0.09
MS-2	Sep-86	223.88	JA-06	Nov-84	60.05	NJ-2	Apr-90	0.23
MS-2	Oct-86	223.75	JA-06	Dec-84	60.01	NJ-2	May-90	0.02
MS-2	Nov-86	225.32	JA-06	Jan-85	59.99	NJ-2	Jun-90	0.13
MS-2	Dec-86	224.72	JA-06	Feb-85	59.95	NJ-2	Jul-90	0.05
MS-2	Jan-87	224.58	JA-06	Apr-85	59.92	NJ-2	Aug-90	-0.01
MS-2	Feb-87	223.78	JA-06	May-85	59.89	NJ-2	Sep-90	0.13
MS-2	Mar-87	224.91	JA-06	Jun-85	59.86	NJ-2	Oct-90	0.03
MS-2	Apr-87	226.33	JA-06	Jul-85	59.76	NJ-2	Nov-90	0.31
MS-2	May-87	228.85	JA-06	Aug-85	59.73	NJ-2	Dec-90	0.03
MS-2	Jun-87	228.65	JA-06	Sep-85	59.02	NJ-2	Jan-91	2.2
MS-2	Jul-87	228.59	JA-06	Oct-85	59.01	NJ-2	Jan-91	-0.05
MS-2	Aug-87	227.23	JA-06	Nov-85	59.72	NJ-2	Feb-91	-0.03
MS-2	Sep-87	226.9	JA-06	Dec-85	59.62	NJ-2	Mar-91	0.04
MS-2	Oct-87	226.56	JA-06	Jan-86	59.61	NJ-2	Apr-91	-0.03
MS-2	Nov-87	225.69	JA-06	Mar-86	59.62	NJ-2	May-91	-0.1
MS-2	Dec-87	224.83	JA-06	Apr-86	59.56	NJ-2	Jun-91	-0.04
MS-2	Jan-88	223.43	JA-06	May-86	59.51	NJ-2	Jul-91	-0.02
MS-2	Feb-88	222.33	JA-06	Jul-86	59.43	NJ-2	Aug-91	0.15
MS-2	Feb-88	244.35	JA-06	Aug-86	59.4	NJ-2	Sep-91	-0.05
MS-2	Mar-88	244.3	JA-06	Sep-86	59.36	NJ-2	Oct-91	0.08
MS-2	Mar-88	244.26	JA-06	Oct-86	59.35	NJ-2	Nov-91	0.07
MS-2	Apr-88	244.15	JA-06	Nov-86	59.31	NJ-2	Dec-91	0.17
MS-2	Jun-88	244.13	JA-06	Dec-86	59.27	NJ-2	Feb-92	-0.05
MS-2	Jul-88	229.1	JA-06	Jan-87	59.18	NJ-2	Mar-92	-0.12
MS-2	Aug-88	228.85	JA-06	Feb-87	59.07	NJ-2	Apr-92	0.02
MS-2	Sep-88	228.63	JA-06	Mar-87	59.19	NJ-2	May-92	-0.08
MS-2	Oct-88	227.94	JA-06	Apr-87	59.18	NJ-2	Jun-92	0.01
MS-2	Nov-88	226.99	JA-06	Jun-87	59.12	NJ-2	Jul-92	-0.03
MS-2	Dec-88	226.42	JA-06	Jul-87	59.09	NJ-2	Aug-92	0.02
MS-2	Jan-89	226.15	JA-06	Aug-87	59.06	NJ-2	Sep-92	-0.1
MS-2	Feb-89	225.35	JA-06	Sep-87	59.08	NJ-2	Oct-92	-0.11
MS-2	Mar-89	224.07	JA-06	Oct-87	59.07	NJ-2	Nov-92	0.32
MS-2	Apr-89	224.54	JA-06	Nov-87	58.98	NJ-2	Dec-92	-0.1
MS-2	May-89	224	JA-06	Dec-87	58.94	NJ-2	Jan-93	-0.06
MS-2	Jun-89	223.39	JA-06	Jan-88	58.93	NJ-2	Feb-93	0.07
MS-2	Jul-89	222.49	JA-06	Feb-88	58.95	NJ-2	Apr-93	-0.19
MS-2	Nov-89	217.65	JA-06	Apr-88	58.97	NJ-2	May-93	-0.21
MS-2	Dec-89	244.02	JA-06	May-88	61.45	NJ-2	Jun-93	-0.23
MS-2	Jan-90	244.01	JA-06	Jun-88	60.61	NJ-2	Jul-93	-0.08
MS-2	Feb-90	244.12	JA-06	Jul-88	61.58	NJ-2	Aug-93	-0.27
MS-2	Mar-90	244.17	JA-06	Aug-88	61 34	NJ-2	Sep-93	-0.21
MS-2	Apr-90	243.87	JA-06	Sep-88	61.4	NJ-2	Oct-93	-0.18
MS-2	May-90	225.2	JA-06	Oct-88	61.37	NJ-2	Nov-93	-0.2
MS-2	Jun-90	224.58	JA-06	Nov-88	60.65	NJ-2	Dec-93	-0.28
MS-2	Jul-90	222.9	JA-06	Dec-88	60.83	NJ-2	Jan-94	-0.24
MS-2	Aug-90	222.66	JA-06	Jan-89	59.73	NJ-2	Mar-94	-0.13
MS-2	Sep-90	221.32	JA-06	Feb-89	59.68	NJ-2	Apr-94	-0.27
MS-2	Oct-90	220.54	JA-06	Mar-89	59.06	NJ-2	May-94	-0.18
MS-2	Nov-90	219.08	JA-06	Apr-89	58.94	NJ-2	Jun-94	-0.16
MS-2	Dec-90	218.03	JA-06	Nov-89	58.78	NJ-2	Jul-94	-0.22
MS-2	Jan-91	217.03	JA-06	Dec-89	58.78	NJ-2	Aug-94	-0.18
MS-2	Feb-91	215.9	JA-06	Feb-90	58.78	NJ-2	Sep-94	-0.26

MS-2	Mar-91	214.9	JA-06	Nov-91	58.85	NJ-2	Oct-94	-0.31
MS-2	Apr-91	244.08	JA-06	Feb-96	61.77	NJ-2	Nov-94	-0.17
MS-2	May-91	222.8	JA-06	Mar-96	62.45	NJ-2	Dec-94	-0.31
MS-2	Jun-91	221.15	JA-06	Apr-96	66.73	NJ-2	Jan-95	-0.36
MS-2	Jul-91	219.14	JA-06	May-96	64.99	NJ-2	Feb-95	-0.23
MS-2	Aug-91	218.28	JA-06	Jun-96	63.87	NJ-2	Mar-95	-0.12
MS-2	Sep-91	216.21	JA-06	Jul-96	63.28	NJ-2	Apr-95	-0.37
MS-2	Oct-91	214.78	JA-06	Aug-96	63.05	NJ-2	May-95	-0.14
MS-2	Nov-91	213.98	JA-06	Sep-96	62.8	NJ-2	Jun-95	-0.14
MS-2	May-92	217.3	JA-06	Oct-96	62.12	NJ-2	Jul-95	-0.24
MS-2	Jun-92	217.36	JA-06	Nov-96	61.74	NJ-2	Sep-95	-0.1
MS-2	Jul-92	217.6	JA-06	Feb-97	60.49	NJ-2	Oct-95	-0.09
MS-2	Aug-92	217.15	JA-06	Mar-97	61.44	NJ-2	Nov-95	-0.09
MS-2	Sep-92	215.6	JA-06	May-97	63.45	NJ-2	Jan-96	0.02
MS-2	Oct-92	214.1	JA-06	Jun-97	62.5	NJ-2	Feb-96	-0.05
MS-2	Nov-92	211.4	JA-06	Jul-97	61.9	NJ-2	Mar-96	-0.08
MS-2	Dec-92	209.1	JA-06	Aug-97	61.6	NJ-2	Apr-96	-0.13
MS-2	Aug-95	244.13	JA-06	Sep-97	61.31	NJ-2	May-96	-0.18
MS-2	Sep-95	216.31	JA-06	Oct-97	61.1	NJ-2	Jun-96	-0.06
MS-2	Oct-95	215.41	JA-06	Jan-98	60.83	NJ-2	Jul-96	-0.1
MS-2	Nov-95	219.84	JA-06	Feb-98	60.92	NJ-2	Aug-96	-0.09
MS-2	Jan-96	244.08	JA-06	Mar-98	61.13	NJ-2	Sep-96	-0.06
MS-2	Feb-96	244.25	JA-06	Apr-98	60.97	NJ-2	Oct-96	-0.05
MS-2	Mar-96	244.3	JA-06	May-98	60.66	NJ-2	Dec-96	0.05
MS-2	Apr-96	244.29	JA-06	Jul-98	60.46	NJ-2	Jan-97	-0.23
MS-2	May-96	225.5	JA-06	Aug-98	60.33	NJ-2	Feb-97	-0.18
MS-2	Jun-96	225.2	JA-06	Sep-98	59.84	NJ-2	Mar-97	0.08
MS-2	Jul-96	224.87	JA-06	Oct-98	59.45	NJ-2	Apr-97	-0.1
MS-2	Aug-96	226.55	JA-06	Nov-98	59.12	NJ-2	May-97	0.19
MS-2	Sep-96	226.52	JA-06	May-99	58.9	NJ-2	Jan-99	0.13
MS-2	Oct-96	225.3	JA-06	Jul-99	58.9	NJ-2	Feb-99	0.19
MS-2	Nov-96	224.92	JA-06	Aug-99	58.9	NJ-2	Mar-99	0.14
MS-2	Dec-96	224.3	EA-1	Jan-82	2.94	NJ-2	Apr-99	0.3
MS-2	Jan-97	223.33	EA-1	Mar-82	3.6	NJ-2	May-99	0.12
MS-2	Feb-97	221.05	EA-1	Apr-82	4.61	NJ-2	Jun-99	0.12
MS-2	Mar-97	222.89	EA-1	May-82	5.13	NJ-2	Jul-99	0.08
MS-2	Apr-97	244.32	EA-1	Jun-82	4.6	NJ-2	Aug-99	-0.18
MS-2	May-97	244.3	EA-1	Jul-82	4.45	NJ-2	Sep-99	-0.15
MS-2	Jun-97	229.86	EA-1	Sep-82	4.35	NJ-2	Oct-99	-0.16
MS-2	Jul-97	228.93	EA-1	Oct-82	4.37	NJ-2	Nov-99	0.05
MS-2	Aug-97	228.32	EA-1	Nov-82	4.49	NJ-2	Dec-99	0.07
MS-2	Sep-97	226.83	EA-1	Dec-82	4.6	NJ-2	Feb-00	-0.04
MS-2	Oct-97	227.26	EA-1	Jan-83	4.66	NJ-2	Mar-00	-0.18
MS-2	Dec-97	232.25	EA-1	Feb-83	4.66	NJ-2	Apr-00	2.13
MS-2	Jan-98	231.43	EA-1	Mar-83	4.79	NJ-2	May-00	0.02
MS-2	Feb-98	231.84	EA-1	Apr-83	4.82	NJ-2	Jan-01	-0.16
MS-2	Mar-98	232.13	EA-1	May-83	5.25	NJ-2	Feb-01	-0.15
MS-2	Apr-98	231.39	EA-1	Jul-83	5	NJ-2	Mar-01	-0.01
MS-2	May-98	229.96	EA-1	Sep-83	4.84	NJ-2	Apr-01	-0.22
MS-2	Jun-98	229.92	EA-1	Oct-83	4.77	NJ-2	May-01	-0.29
MS-2	Jul-98	229.84	EA-1	Jan-84	4.75	NJ-2	Jun-01	-0.24
MS-2	Aug-98	229.75	EA-1	Feb-84	4.65	NJ-2	Aug-01	-0.38
MS-2	Sep-98	229.71	EA-1	Apr-84	4.66	NJ-2	Sep-01	-0.33

MS-2	Oct-98	229.4	EA-1	May-84	4.55	NJ-2	Oct-01	-0.26
MS-2	Nov-98	229.15	EA-1	Jul-84	4.38	NJ-2	Nov-01	-0.23
MS-2	Dec-98	228.91	EA-1	Aug-84	4.19	NJ-2	Dec-01	-0.3
MS-2	Jan-99	231.79	EA-1	Oct-84	4.01	NJ-2	Jan-02	-0.37
MS-2	Feb-99	228.66	EA-1	Nov-84	3.88	NJ-2	Feb-02	-0.33
MS-2	Mar-99	230.61	EA-1	Dec-84	3.75	NJ-2	Mar-02	-0.41
MS-2	Apr-99	231.79	EA-1	Jan-85	3.68	NJ-2	Apr-02	-0.35
MS-2	May-99	230.9	EA-1	Feb-85	3.6	NJ-2	May-02	-0.36
MS-2	Jun-99	230.86	EA-1	Mar-85	3.5	NJ-2	Jun-02	-0.64
MS-2	Jul-99	230.58	EA-1	Apr-85	3.41	NJ-2	Jul-02	-0.75
MS-2	Aug-99	230.13	EA-1	May-85	3.27	NJ-2	Sep-02	-0.41
MS-2	Sep-99	229.8	EA-1	Jun-85	3.13	NJ-2	Oct-02	-0.38
MS-2	Oct-99	229.57	EA-1	Jul-85	3	NJ-2	Dec-02	-0.91
MS-2	Nov-99	229.35	EA-1	Aug-85	2.9	NJ-2	Feb-03	-0.31
MS-2	Dec-99	229.22	EA-1	Sep-85	2.82	NJ-2	Mar-03	-0.32
MS-2	Feb-00	228.85	EA-1	Oct-85	2.4	NJ-2	Apr-03	-0.3
MS-2	Mar-00	228.8	EA-1	Nov-85	2.53	NJ-2	May-03	-0.4
MS-2	Apr-00	228.67	EA-1	Dec-85	2.58	NJ-3	Nov-87	41.87
MS-2	May-00	228.54	EA-1	Jan-86	2.51	NJ-3	Dec-89	42.19
MS-2	Jan-01	227.8	EA-1	Feb-86	2.46	NJ-3	Jan-90	42.39
MS-2	Feb-01	227.82	EA-1	Mar-86	2.43	NJ-3	Feb-90	42.69
MS-2	Mar-01	227.76	EA-1	Apr-86	2.36	NJ-3	Feb-90	42.73
MS-2	Apr-01	227.78	EA-1	May-86	2.3	NJ-3	Mar-90	42.85
MS-2	May-01	227.7	EA-1	Jun-86	2.18	NJ-3	Apr-90	42.88
MS-2	Jun-01	227.61	EA-1	Jul-86	2.15	NJ-3	May-90	42.91
MS-2	Aug-01	227.4	EA-1	Aug-86	2.03	NJ-3	Jun-90	43.27
MS-2	Sep-01	227.32	EA-1	Sep-86	1.97	NJ-3	Jul-90	43.37
MS-2	Oct-01	227.27	EA-1	Sep-86	-2	NJ-3	Aug-90	43.44
MS-2	Dec-01	227.22	EA-1	Oct-86	1.9	NJ-3	Sep-90	43.54
MS-2	Jan-02	227.23	EA-1	Nov-86	1.83	NJ-3	Oct-90	43.49
MS-2	Feb-02	227.26	EA-1	Dec-86	1.77	NJ-3	May-92	43.54
MS-2	Mar-02	227.27	EA-1	Jan-87	1.74	NJ-3	Jun-92	43.44
MS-2	Apr-02	227.34	EA-1	Feb-87	1.69	NJ-3	Jul-92	43.34
MS-2	May-02	227.49	EA-1	Mar-87	1.65	NJ-3	Aug-92	43.2
MS-2	Jun-02	227.5	EA-1	Apr-87	2.14	NJ-3	Sep-92	43.11
MS-2	Jul-02	227.46	EA-1	May-87	2.21	NJ-3	Oct-92	42.95
MS-2	Aug-02	227.47	EA-1	Jun-87	2.13	NJ-3	Nov-92	42.83
MS-2	Sep-02	227.39	EA-1	Jul-87	2.07	NJ-3	Dec-92	42.6
MS-2	Oct-02	227.36	EA-1	Aug-87	1.9	NJ-3	Jan-93	42.42
MS-2	Nov-02	228.74	EA-1	Sep-87	1.86	NJ-3	Feb-93	42.32
MS-2	Dec-02	230.98	EA-1	Oct-87	1.79	NJ-3	Mar-93	42.18
MS-2	Jan-03	229.87	EA-1	Nov-87	1.74	NJ-3	Apr-93	42.06
W-1	Jan-82	196.13	EA-1	Dec-87	1.73	NJ-3	May-93	41.92
W-1	Apr-82	198.96	EA-1	Jan-88	1.74	NJ-3	Jun-93	41.72
W-1	May-82	198.32	EA-1	Feb-88	1.74	NJ-3	Jul-93	41.45
W-1	May-82	198.5	EA-1	Feb-88	3.05	NJ-3	Sep-93	41.35
W-1	Jun-82	198.28	EA-1	Mar-88	6.13	NJ-3	Oct-93	41.23
W-1	Sep-82	197.72	EA-1	Mar-88	5.96	NJ-3	Nov-93	41.13
W-1	Oct-82	197.47	EA-1	Apr-88	5.9	NJ-3	Dec-93	41.05
W-1	Jan-83	197.25	EA-1	May-88	5.97	NJ-3	Jan-94	40.94
W-1	Feb-83	197.4	EA-1	Jun-88	5.92	NJ-3	Jan-97	43.62
W-1	Mar-83	197.3	EA-1	Jul-88	5.85	NJ-3	Feb-97	43.93
W-1	Apr-83	197.4	EA-1	Aug-88	5.9	NJ-3	Mar-97	44.15

W-1	May-83	198.16	EA-1	Sep-88	6.24	NJ-3	Apr-97	44.33
W-1	Jun-83	198.2	EA-1	Oct-88	6.36	NJ-3	May-97	44.23
W-1	Jul-83	198.06	EA-1	Nov-88	6.44	NJ-3	Jan-99	44.09
W-1	Sep-83	197.71	EA-1	Dec-88	6.53	NJ-3	Feb-99	43.9
W-1	Feb-84	197.05	EA-1	Jan-89	6.6	NJ-3	Mar-99	44.08
W-1	Apr-84	196.91	EA-1	Feb-89	6.56	NJ-3	Apr-99	44.14
W-1	May-84	197.2	EA-1	Mar-89	6.54	NJ-3	May-99	40.95
W-1	Jul-84	196.61	EA-1	Apr-89	6.43	NJ-3	Jun-99	44.17
W-1	Sep-84	196.86	EA-1	May-89	6.38	NJ-3	Jul-99	44.15
W-1	Oct-84	196.34	EA-1	Jun-89	5.99	NJ-3	Aug-99	43.96
W-1	Nov-84	196.3	EA-1	Jul-89	5.91	NJ-3	Sep-99	40.15
W-1	Dec-84	196.02	EA-1	Aug-89	5.52	NJ-3	Oct-99	39.89
W-1	Jan-85	196.07	EA-1	Nov-89	4.73	NJ-3	Nov-99	43.89
W-1	Feb-85	196.45	EA-1	Dec-89	4.72	NJ-3	Dec-99	43.73
W-1	Mar-85	195.79	EA-1	Jan-90	5.25	NJ-3	Feb-00	43.48
W-1	Apr-85	195.6	EA-1	Feb-90	5.19	NJ-3	Mar-00	43.37
W-1	May-85	195.35	EA-1	Mar-90	6.68	NJ-3	Apr-00	43.19
W-1	Aug-85	195.45	EA-1	Apr-90	6.69	NJ-3	May-00	43.02
W-1	Sep-85	195.47	EA-1	May-90	6.66	NJ-3	Jan-01	43.59
W-1	Oct-85	195.42	EA-1	Jun-90	6.46	NJ-3	Feb-01	41.61
W-1	Nov-85	195.36	EA-1	Jul-90	6.41	NJ-3	Mar-01	41.49
W-1	Dec-85	195.39	EA-1	Aug-90	6.48	NJ-3	Apr-01	41.41
W-1	Jan-86	195.5	EA-1	Sep-90	6.5	NJ-3	May-01	41.11
W-1	Feb-86	195.42	EA-1	Oct-90	6.57	NJ-3	Jun-01	40.98
W-1	Mar-86	195.41	EA-1	Nov-90	6.58	NJ-3	Aug-01	40.77
W-1	Apr-86	194.84	EA-1	Dec-90	6.61	NJ-3	Sep-01	40.72
W-1	May-86	192.68	EA-1	Jan-91	6.57	NJ-3	Oct-01	40.72
W-1	Jul-86	193.94	EA-1	Feb-91	6.51	NJ-4	Mar-97	98.9
W-1	Aug-86	193.88	EA-1	Mar-91	6.48	NJ-4	Apr-97	99.53
W-1	Oct-86	192.88	EA-1	Apr-91	7.55	NJ-4	May-97	98.6
W-1	Nov-86	194.03	EA-1	May-91	7.26	NJ-4	Jun-99	98.6
W-1	Dec-86	193.98	EA-1	Jun-91	7	NJ-4	Jul-99	98.6
W-1	Jan-87	192.83	EA-1	Jul-91	6.72	NJ-4	Oct-99	83.85
W-1	Feb-87	192.77	EA-1	Aug-91	6.45	NJ-5	Nov-89	146.35
W-1	Mar-87	192.81	EA-1	Sep-91	6.22	NJ-5	Dec-89	149.49
W-1	Apr-87	195.85	EA-1	Oct-91	6.04	NJ-5	Jan-90	156.65
W-1	May-87	194.82	EA-1	Nov-91	5.97	NJ-5	Feb-90	157.45
W-1	Jun-87	194.75	EA-1	Jun-92	5.2	NJ-5	Feb-90	155.37
W-1	Jul-87	195.71	EA-1	Jul-92	4.94	NJ-5	Mar-90	157.74
W-1	Aug-87	195.74	EA-1	Aug-92	4.7	NJ-5	May-90	157.05
W-1	Sep-87	196.06	EA-1	Sep-92	4.53	NJ-5	Jun-90	156.73
W-1	Oct-87	196.21	EA-1	Oct-92	4.29	NJ-5	Jul-90	156.56
W-1	Nov-87	196.31	EA-1	Nov-92	4.21	NJ-5	Aug-90	157
W-1	Dec-87	196.15	EA-1	Dec-92	3.87	NJ-5	Sep-90	156.19
W-1	Jan-88	196.24	EA-1	Jan-93	3.79	NJ-5	Oct-90	155.34
W-1	Feb-88	192.6	EA-1	Feb-93	3.67	NJ-5	Nov-90	154.43
W-1	Feb-88	200.5	EA-1	Mar-93	3.63	NJ-5	Dec-90	152.82
W-1	Mar-88	200.9	EA-1	Apr-93	3.53	NJ-5	Jan-91	144.93
W-1	Mar-88	199.76	EA-1	May-93	3.39	NJ-5	Feb-91	149.61
W-1	Apr-88	198.95	EA-1	Jun-93	3.21	NJ-5	Mar-91	148.74
W-1	Jun-88	195.95	EA-1	Jul-93	3.02	NJ-5	Apr-91	156.71
W-1	Jul-88	198.4	EA-1	Aug-93	2.83	NJ-5	May-91	156.04
W-1	Aug-88	198.07	EA-1	Sep-93	2.72	NJ-5	Jun-91	155.22

W-1	Sep-88	198.03	EA-1	Oct-93	2.04	NJ-5	Jul-91	152.01
W-1	Oct-88	197.85	EA-1	Nov-93	2.5	NJ-5	Aug-91	150.51
W-1	Nov-88	197.27	EA-1	Dec-93	2.41	NJ-5	Sep-91	148.54
W-1	Dec-88	195.93	EA-1	Jan-94	2.32	NJ-5	Oct-91	147.17
W-1	Jan-89	195.85	EA-1	Feb-94	2.14	NJ-5	Nov-91	146.14
W-1	Feb-89	197.4	EA-1	Mar-94	1.94	NJ-5	May-92	156.08
W-1	Mar-89	197.05	EA-1	Apr-94	1.86	NJ-5	Jun-92	155.4
W-1	Apr-89	197.78	EA-1	May-94	1.74	NJ-5	Jul-92	153.51
W-1	May-89	195.6	EA-1	Jun-94	1.61	NJ-5	Aug-92	151.76
W-1	Jun-89	196.17	EA-1	Jul-94	1.3	NJ-5	Sep-92	150.56
W-1	Jul-89	196.98	EA-1	Aug-94	1.42	NJ-5	Oct-92	148.92
W-1	Nov-89	195.76	EA-1	Sep-94	1.35	NJ-5	Nov-92	147.4
W-1	Dec-89	197.65	EA-1	Oct-94	1.34	NJ-5	Dec-92	145.96
W-1	Jan-90	195.4	EA-1	Nov-94	1.32	NJ-5	Jan-93	145.17
W-1	Feb-90	197.72	EA-1	Dec-94	1.19	NJ-5	Feb-93	144.41
W-1	Mar-90	200.16	EA-1	Jan-95	1.4	NJ-5	Mar-93	144.75
W-1	Apr-90	196.72	EA-1	Feb-95	1.29	NJ-5	Apr-93	145.84
W-1	May-90	196.82	EA-1	Mar-95	1.17	NJ-5	May-93	146.95
W-1	Jun-90	197.89	EA-1	Apr-95	1.05	NJ-5	Jun-93	146.87
W-1	Jul-90	196.5	EA-1	May-95	1.01	NJ-5	Jul-93	145.95
W-1	Aug-90	196.87	EA-1	Jun-95	0.89	NJ-5	Sep-93	143.17
W-1	Sep-90	196.92	EA-1	Jul-95	0.73	NJ-5	Oct-93	142.1
W-1	Oct-90	196.81	EA-1	Aug-95	3.65	NJ-5	Nov-93	141.09
W-1	Dec-90	196.03	EA-1	Sep-95	4.35	NJ-5	Dec-93	140.6
W-1	Jan-91	196.98	EA-1	Oct-95	3.79	NJ-5	Jan-94	140.03
W-1	Jan-91	197.08	EA-1	Nov-95	3.44	NJ-5	Feb-94	140.2
W-1	Mar-91	197.71	EA-1	Jan-96	5.77	NJ-5	Mar-94	139.9
W-1	Apr-91	198.67	EA-1	Feb-96	6.1	NJ-5	Apr-94	139.82
W-1	May-91	198.29	EA-1	Mar-96	5.64	NJ-5	May-94	139.79
W-1	Jun-91	198.33	EA-1	Apr-96	8.5	NJ-5	Jun-94	139.66
W-1	Jul-91	198.3	EA-1	May-96	7.98	NJ-5	Jul-94	140.07
W-1	Aug-91	197.35	EA-1	Jun-96	7.85	NJ-5	Aug-94	140.72
W-1	Sep-91	195.22	EA-1	Jul-96	7.75	NJ-5	Sep-94	143.33
W-1	Oct-91	196.65	EA-1	Aug-96	8.04	NJ-5	Oct-94	145.4
W-1	Nov-91	196.75	EA-1	Sep-96	8.1	NJ-5	Nov-94	147.69
W-1	May-92	194.95	EA-1	Oct-96	8.09	NJ-5	Dec-94	148.74
W-1	Jun-92	195.1	EA-1	Nov-96	8.18	NJ-5	Jan-95	149.22
W-1	Jul-92	194.35	EA-1	Dec-96	8.17	NJ-5	Feb-95	148.52
W-1	Aug-92	196	EA-1	Jan-97	8.25	NJ-5	Mar-95	147.05
W-1	Sep-92	196.56	EA-1	Feb-97	8.31	NJ-5	Apr-95	146.11
W-1	Oct-92	193.32	EA-1	Mar-97	8.6	NJ-5	May-95	146.22
W-1	Nov-92	193.83	EA-1	Apr-97	11.09	NJ-5	Jun-95	146.81
W-1	Dec-92	196.4	EA-1	May-97	11.66	NJ-5	Jul-95	146.61
W-1	Jan-93	196.38	EA-1	Jun-97	10.76	NJ-5	Aug-95	157.57
W-1	Feb-93	196.3	EA-1	Jul-97	10.2	NJ-5	Sep-95	157.66
W-1	Mar-93	195.82	EA-1	Aug-97	9.84	NJ-5	Oct-95	157.3
W-1	Apr-93	195	EA-1	Sep-97	9.57	NJ-5	Nov-95	156.75
W-1	May-93	194.8	EA-1	Oct-97	9.49	NJ-5	Jan-96	157.44
W-1	Jun-93	193.2	EA-1	Jan-98	10.14	NJ-5	Feb-96	154.89
W-1	Jul-93	194.5	EA-1	Feb-98	10.28	NJ-5	Mar-96	157.6
W-1	Aug-93	191.7	EA-1	Mar-98	10.6	NJ-5	Apr-96	157.73
W-1	Sep-93	194.8	EA-1	Apr-98	10.28	NJ-5	May-96	157.58
W-1	Oct-93	194.7	EA-1	May-98	10.08	NJ-5	Jun-96	157.73

W-1	Nov-93	194.85	EA-1	Jun-98	9.45	NJ-5	Jul-96	157.96
W-1	Dec-93	193.45	EA-1	Jul-98	9.34	NJ-5	Aug-96	157.62
W-1	Jan-94	195.2	EA-1	Aug-98	9.16	NJ-5	Sep-96	156.88
W-1	Feb-94	192.71	EA-1	Sep-98	8.91	NJ-5	Oct-96	155.83
W-1	Mar-94	192.6	EA-1	Oct-98	8.72	NJ-5	Nov-96	154.85
W-1	Apr-94	191.85	EA-1	Nov-98	8.45	NJ-5	Dec-96	153.3
W-1	May-94	191.3	EA-1	Dec-98	8.23	NJ-5	Jan-97	151.67
W-1	Jun-94	190.8	EA-1	Jan-99	8.02	NJ-5	Feb-97	152.42
W-1	Jul-94	191.92	EA-1	Feb-99	7.93	NJ-5	Mar-97	156.92
W-1	Aug-94	191.49	EA-1	Mar-99	7.95	NJ-5	Apr-97	159.85
W-1	Sep-94	191.6	EA-1	Apr-99	7.89	NJ-5	May-97	160.88
W-1	Oct-94	191.25	EA-1	May-99	7.58	NJ-5	Jan-99	150.14
W-1	Nov-94	191.13	EA-1	Jun-99	7.35	NJ-5	Feb-99	148.65
W-1	Dec-94	191.05	EA-1	Jul-99	6.94	NJ-5	Mar-99	151.63
W-1	Jan-95	193.96	EA-1	Aug-99	6.64	NJ-5	May-99	152.03
W-1	Feb-95	191.3	EA-1	Sep-99	6.33	NJ-5	Jun-99	150.43
W-1	Mar-95	191.9	EA-1	Oct-99	6.08	NJ-5	Jul-99	148.75
W-1	Apr-95	191.2	EA-1	Nov-99	5.83	NJ-5	Aug-99	147.25
W-1	May-95	191.58	EA-1	Dec-99	5.61	NJ-5	Sep-99	146.38
W-1	Jun-95	192.52	EA-1	Feb-00	5.22	NJ-5	Oct-99	146.05
W-1	Jul-95	189.66	EA-1	Mar-00	5.09	NJ-5	Nov-99	145.55
W-1	Aug-95	198.53	EA-1	Apr-00	4.8	NJ-5	Dec-99	145.58
W-1	Sep-95	198.57	EA-1	Jul-00	4.1	NJ-5	Feb-00	145.3
W-1	Oct-95	198.23	EA-1	Aug-00	3.79	NJ-5	Mar-00	144.4
W-1	Nov-95	197.55	EA-1	Sep-00	3.62	NJ-5	Apr-00	143.51
W-1	Jan-96	199	EA-1	Oct-00	3.43	NJ-5	May-00	143.11
W-1	Feb-96	199.45	EA-1	Nov-00	3.26	NJ-5	Jan-01	142.65
W-1	Mar-96	199.35	EA-1	Dec-00	3.14	NJ-5	Feb-01	142.24
W-1	Apr-96	198.57	EA-1	Jan-01	3.02	NJ-5	Mar-01	141.59
W-1	May-96	198.7	EA-1	Feb-01	3.95	NJ-5	Apr-01	141.12
W-1	Jun-96	197.7	EA-1	Mar-01	2.78	NJ-5	May-01	140.67
W-1	Jul-96	198.18	EA-1	Apr-01	2.66	NJ-5	Jun-01	140.39
W-1	Aug-96	197.25	EA-1	May-01	2.5	NJ-5	Aug-01	141.19
W-1	Sep-96	197.24	EA-1	Jun-01	2.41	NJ-5	Sep-01	140.88
W-1	Oct-96	196.7	EA-1	Aug-01	1.94	NJ-5	Oct-01	143.62
W-1	Nov-96	196.42	EA-1	Sep-01	1.7	NJ-5	Dec-01	143
W-1	Dec-96	197.25	EA-1	Oct-01	1.7	NJ-5	Jan-02	143.08
W-1	Jan-97	197.22	EA-1	Nov-01	1.66	NJ-5	Feb-02	142.77
W-1	Feb-97	196.39	EA-1	Dec-01	1.62	NJ-5	Mar-02	142.07
W-1	Mar-97	196.1	EA-1	Jan-02	1.63	NJ-5	Apr-02	142.12
W-1	Apr-97	197.99	EA-1	Feb-02	1.35	NJ-5	May-02	144.62
W-1	May-97	198.35	EA-1	Mar-02	1.4	NJ-5	Jun-02	143.27
W-1	Jun-97	198.25	EA-1	Apr-02	1.31	NJ-5	Jul-02	142.46
W-1	Jul-97	198.15	EA-1	May-02	1.32	NJ-5	Aug-02	143.14
W-1	Aug-97	197.14	EA-1	Jun-02	1.03	NJ-5	Sep-02	144.01
W-1	Sep-97	196.55	EA-1	Jul-02	0.84	NJ-5	Oct-02	143.81
W-1	Oct-97	197.54	EA-1	Sep-02	0.72	NJ-5	Nov-02	144.53
W-1	Dec-97	198.55	EA-1	Oct-02	0.64	NJ-5	Dec-02	144.33
W-1	Jan-98	198.38	EA-1	Nov-02	0.6	NJ-5	Jan-03	143.72
W-1	Feb-98	197.6	EA-1	Jan-03	0.61	NJ-7	Mar-96	73.28
W-1	Mar-98	197.32	EA-1	Feb-03	0.63	NJ-7	Apr-96	77.36
W-1	Apr-98	197.06	EA-1	Mar-03	0.56	NJ-7	May-96	75.9
W-1	May-98	196.97	EA-1	Apr-03	0.52	NJ-7	Jun-96	74.7

W-1	Jun-98	196.88	EA-1	May-03	0.47	NJ-7	Jul-96	73.63
W-1	Jul-98	196.92	EA-1	Jun-03	0.33	NJ-7	Aug-96	73.54
W-1	Aug-98	197.4	SALLAN HAN	May-82	1	NJ-7	Sep-96	72.85
W-1	Sep-98	196.11	SALLAN HAN	Jul-82	0.95	NJ-7	Oct-96	72.01
W-1	Oct-98	196.33	SALLAN HAN	Jul-82	1.01	NJ-7	Dec-96	70.07
W-1	Nov-98	196.82	SALLAN HAN	Sep-82	0.96	NJ-7	Jan-97	69.3
W-1	Dec-98	195.73	SALLAN HAN	Oct-82	0.88	NJ-7	Feb-97	68.43
W-1	Feb-99	196.62	SALLAN HAN	Nov-82	0.94	NJ-7	Mar-97	68.42
W-1	Mar-99	196.25	SALLAN HAN	Dec-82	1.01	NJ-7	Apr-97	71.24
W-1	Jun-99	195.74	SALLAN HAN	Jan-83	1.09	NJ-7	May-97	75.25
W-1	Sep-99	196.35	SALLAN HAN	Feb-83	1.04	NJ-7	Jun-97	73.5
W-1	Dec-99	196.07	SALLAN HAN	Mar-83	1.19	NJ-7	Jul-97	73.52
W-1	Mar-00	193.7	SALLAN HAN	Apr-83	1.19	NJ-7	Jan-98	69.37
W-2	Oct-96	190.6	SALLAN HAN	May-83	1.1	NJ-7	Feb-98	72.55
W-2	Jun-97	192.04	SALLAN HAN	Jul-83	0.82	NJ-7	Mar-98	70.46
W-2	Jul-97	191.31	SALLAN HAN	Sep-83	1	NJ-7	Apr-98	69.82
W-2	Aug-97	191	SALLAN HAN	Oct-83	0.9	NJ-7	May-98	69.27
W-2	Sep-97	190.74	SALLAN HAN	Jan-84	1.06	NJ-7	Jun-98	68.65
W-2	Oct-97	190.55	SALLAN HAN	Feb-84	1.03	NJ-7	Jul-98	68.13
W-2	Dec-97	192.05	SALLAN HAN	Apr-84	1.01	NJ-7	Aug-98	68.07
W-2	Jan-98	191.65	SALLAN HAN	May-84	0.77	NJ-7	Sep-98	67.6
W-2	Feb-98	191.3	SALLAN HAN	Jul-84	0.76	NJ-7	Jun-99	67.13
W-2	Mar-98	191.28	SALLAN HAN	Aug-84	0.81	NJ-7	Jul-99	67.13
W-2	Apr-98	191.07	SALLAN HAN	Oct-84	0.81	NJ-7	Aug-99	67.13
W-2	May-98	190.9	SALLAN HAN	Nov-84	0.83	NJ-7	Nov-99	67.1
W-2	Jun-98	190.84	SALLAN HAN	Dec-84	0.93	NJ-7	Dec-99	67.1
W-2	Jul-98	190.6	SALLAN HAN	Jan-85	1.03	NJ-7	Jan-01	67.2
W-2	Aug-98	190.45	SALLAN HAN	Feb-85	1.03	NJ-7	Feb-01	67.2
W-2	Sep-98	190.17	SALLAN HAN	Mar-85	1.07	NJ-9	Sep-96	7.66
W-2	Oct-98	190.08	SALLAN HAN	Apr-85	0.91	NJ-9	Oct-96	7.69
W-2	Nov-98	189.92	SALLAN HAN	May-85	0.8	NJ-9	Nov-96	7.79
W-2	Dec-98	189.85	SALLAN HAN	Jun-85	0.77	NJ-9	Dec-96	7.94
W-2	Jan-99	189.66	SALLAN HAN	Sep-85	0.41	NJ-9	Jan-97	8.14
W-2	Feb-99	189.53	SALLAN HAN	Oct-85	0.73	NJ-9	Feb-97	8.34
W-2	Mar-99	190.6	SALLAN HAN	Nov-85	0.71	NJ-9	Mar-97	8.43
W-2	Apr-99	190.3	SALLAN HAN	Dec-85	0.72	NJ-9	Apr-97	8.73
W-2	May-99	190.2	SALLAN HAN	Jan-86	0.71	NJ-9	May-97	9.63
W-2	Jun-99	189.8	SALLAN HAN	Feb-86	0.73	NJ-9	Jun-97	9.35
W-2	Jul-99	189.5	SALLAN HAN	Mar-86	0.72	NJ-9	Jul-97	9.42
W-2	Aug-99	189.18	SALLAN HAN	Apr-86	0.77	NJ-9	Aug-97	9.27
W-2	Sep-99	189.12	SALLAN HAN	May-86	0.76	NJ-9	Sep-97	9.35
W-2	Oct-99	188.98	SALLAN HAN	Jun-86	0.58	NJ-9	Oct-97	9.32
W-2	Nov-99	188.5	SALLAN HAN	Jul-86	0.62	NJ-9	Nov-97	9.52
W-2	Dec-99	188.5	SALLAN HAN	Aug-86	0.61	NJ-9	Dec-97	9.78
W-2	Feb-00	188.14	SALLAN HAN	Sep-86	0.59	NJ-9	Jan-98	9.86
W-2	Mar-00	187.57	SALLAN HAN	Oct-86	0.54	NJ-9	Feb-98	9.94
W-2	Apr-00	187.3	SALLAN HAN	Nov-86	0.57	NJ-9	Mar-98	10.27
W-2	May-00	187.29	SALLAN HAN	Dec-86	0.58	NJ-9	Apr-98	10.20
WJ-4	Dec-81	258.12	SALLAN HAN	Jan-87	0.43	NJ-9	May-98	10.20
WJ-4	Jan-82	268.73	SALLAN HAN	Feb-87	0.58	NJ-9	Jun-98	9.96
WJ-4	Feb-82	264.43	SALLAN HAN	Mar-87	0.66	NJ-9	Jul-98	9.73
WJ-4	Apr-82	263.96	SALLAN HAN	Apr-87	0.89	NJ-9	Aug-98	9.61
WJ-4	May-82	263.71	SALLAN HAN	May-87	0.78	NJ-9	Sep-98	9.55

WJ-4	May-82	263.54	SALLAN HAN	Jun-87	0.79	NJ-9	Oct-98	9.54
WJ-4	Jun-82	262.23	SALLAN HAN	Jul-87	0.67	NJ-9	Nov-98	9.42
WJ-4	Jul-82	261.5	SALLAN HAN	Aug-87	0.58	NJ-9	Dec-98	9.54
WJ-4	Aug-82	260.8	SALLAN HAN	Sep-87	0.6	NJ-9	Jan-99	9.66
WJ-4	Sep-82	260.37	SALLAN HAN	Oct-87	0.59	NJ-9	Feb-99	9.74
WJ-4	Oct-82	261.88	SALLAN HAN	Nov-87	0.43	NJ-9	Mar-99	9.66
WJ-4	Nov-82	262.41	SALLAN HAN	Dec-87	0.44	NJ-9	Apr-99	9.75
WJ-4	Jan-83	260.59	SALLAN HAN	Jan-88	0.43	NJ-9	May-99	9.60
WJ-4	Feb-83	264.13	SALLAN HAN	Feb-88	0.7	NJ-9	Jun-99	9.35
WJ-4	Mar-83	266.72	SALLAN HAN	Feb-88	2.22	NJ-9	Jul-99	9.17
WJ-4	Mar-83	263.52	SALLAN HAN	Mar-88	1.7	NJ-9	Aug-99	9.05
WJ-4	Apr-83	263.91	SALLAN HAN	Mar-88	1.45	NJ-9	Sep-99	8.92
WJ-4	May-83	263.19	SALLAN HAN	Apr-88	1.44	NJ-9	Oct-99	8.85
WJ-4	Jun-83	261.56	SALLAN HAN	May-88	1.32	NJ-9	Nov-99	8.72
WJ-4	Jul-83	259.3	SALLAN HAN	Jun-88	1.05	NJ-9	Dec-99	8.69
WJ-4	Sep-83	263.4	SALLAN HAN	Jul-88	-1.69	NJ-9	Jan-00	7.86
WJ-4	Nov-83	260.41	SALLAN HAN	Aug-88	0.98	NJ-9	Feb-00	9.49
WJ-4	Jan-84	259.73	SALLAN HAN	Sep-88	1.04	NJ-9	Mar-00	8.82
WJ-4	Feb-84	259.02	SALLAN HAN	Oct-88	0.95	NJ-9	Apr-00	8.66
WJ-4	Apr-84	258.81	SALLAN HAN	Nov-88	0.96	NJ-9	May-00	8.06
WJ-4	May-84	258.08	SALLAN HAN	Dec-88	1.02	NJ-9	Jun-00	7.88
WJ-4	Jul-84	257.35	SALLAN HAN	Jan-89	1.09	NJ-9	Jul-00	7.72
WJ-4	Sep-84	256.16	SALLAN HAN	Feb-89	0.95	NJ-9	Aug-00	7.51
WJ-4	Oct-84	258.27	SALLAN HAN	Mar-89	1.2	NJ-9	Sep-00	7.35
WJ-4	Nov-84	257.62	SALLAN HAN	Apr-89	1.23	NJ-9	Oct-00	7.19
WJ-4	Dec-84	257.05	SALLAN HAN	May-89	0.7	NJ-9	Nov-00	7.07
WJ-4	Jan-85	256.31	SALLAN HAN	Jun-89	0.59	NJ-9	Dec-00	7.05
WJ-4	Feb-85	255.82	SALLAN HAN	Jul-89	0.87	NJ-9	Jan-01	7.06
WJ-4	Mar-85	255.66	SALLAN HAN	Aug-89	0.92	NJ-9	Feb-01	6.91
WJ-4	Apr-85	255.73	SALLAN HAN	Dec-89	1.07	NJ-9	Mar-01	6.80
WJ-4	May-85	255.65	SALLAN HAN	Jan-90	1.25	NJ-9	Apr-01	6.65
WJ-4	Jun-85	255.73	SALLAN HAN	Feb-90	1.17	NJ-9	May-01	6.41
WJ-4	Jul-85	255.19	SALLAN HAN	Mar-90	1.48	NJ-9	Jun-01	6.22
WJ-4	Aug-85	254.57	SALLAN HAN	May-90	1.15	NJ-9	Aug-01	5.84
WJ-4	Sep-85	253.82	SALLAN HAN	Jun-90	1.04	NJ-9	Sep-01	5.74
WJ-4	Oct-85	253.15	SALLAN HAN	Jul-90	0.72	NJ-9	Oct-01	5.63
WJ-4	Nov-85	252.96	SALLAN HAN	Aug-90	0.69	NJ-9	Jan-02	5.59
WJ-4	Dec-85	252.27	SALLAN HAN	Sep-90	1.03	NJ-9	Feb-02	5.50
WJ-4	Jan-86	251.89	SALLAN HAN	Nov-90	1.04	NJ-9	Mar-02	5.46
WJ-4	Feb-86	251.65	SALLAN HAN	Dec-90	1.05	NJ-9	Apr-02	5.38
WJ-4	Mar-86	254	SALLAN HAN	Jan-91	1.17	NJ-9	May-02	5.06
WJ-4	Apr-86	255.35	SALLAN HAN	Feb-91	1.15	NJ-9	Jun-02	4.97
WJ-4	May-86	257.52	SALLAN HAN	Mar-91	1.2	NJ-9	Jul-02	4.85
WJ-4	Jun-86	257.91	SALLAN HAN	Apr-91	1.12	NJ-9	Aug-02	4.77
WJ-4	Jul-86	257.55	SALLAN HAN	May-91	0.9	NJ-9	Sep-02	4.71
WJ-4	Aug-86	258.45	SALLAN HAN	Jun-91	0.3	NJ-9	Oct-02	4.69
WJ-4	Sep-86	258.88	SALLAN HAN	Jul-91	1.08	NJ-9	Nov-02	4.86
WJ-4	Oct-86	258.87	SALLAN HAN	Aug-91	-0.4	NJ-9	Dec-02	4.85
WJ-4	Nov-86	259.99	SALLAN HAN	Sep-91	1.08	NJ-9	Jan-03	4.89
WJ-4	Dec-86	259.05	SALLAN HAN	Oct-91	1.01	NJ-9	Feb-03	4.88
WJ-4	Feb-87	257.85	SALLAN HAN	Nov-91	1.08	NJ-9	Mar-03	4.75
WJ-4	Apr-87	263.88	SALLAN HAN	May-92	1	NJ-9	Apr-03	4.81
WJ-4	May-87	262.73	SALLAN HAN	Jun-92	-0.49	NJ-9	May-03	4.73

WJ-4	Jun-87	261.83	SALLAN HAN	Jul-92	0.88	NJ-10	May-99	0.66
WJ-4	Jul-87	260.42	SALLAN HAN	Aug-92	-0.44	NJ-10	Jun-99	0.86
WJ-4	Sep-87	263.02	SALLAN HAN	Sep-92	0.8	NJ-10	Jul-99	0.7
WJ-4	Oct-87	260.6	SALLAN HAN	Oct-92	0.78	NJ-10	Aug-99	0.77
WJ-4	Nov-87	259.54	SALLAN HAN	Nov-92	0.86	NJ-10	Sep-99	0.71
WJ-4	Jan-88	258.72	SALLAN HAN	Dec-92	0.95	NJ-10	Oct-99	0.65
WJ-4	Feb-88	258.41	SALLAN HAN	Jan-93	0.98	NJ-10	Dec-99	0.44
WJ-4	Feb-88	265.46	SALLAN HAN	Feb-93	1.1	NJ-10	Feb-00	0.63
WJ-4	Mar-88	264.36	SALLAN HAN	Mar-93	0.92	NJ-10	Mar-00	0.5
WJ-4	Mar-88	264.8	SALLAN HAN	Apr-93	0.44	NJ-10	Apr-00	0.68
WJ-4	Apr-88	264.05	SALLAN HAN	May-93	0.73	NJ-10	May-00	0.55
WJ-4	May-88	264.29	SALLAN HAN	Jun-93	0.64	NJ-10	Jan-01	0.44
WJ-4	Jun-88	263.98	SALLAN HAN	Jul-93	-0.07	NJ-10	Feb-01	0.3
WJ-4	Jul-88	263.85	SALLAN HAN	Aug-93	-1.07	NJ-11	Jan-97	-0.60
WJ-4	Aug-88	264.12	SALLAN HAN	Sep-93	0.6	NJ-11	Feb-97	-0.45
WJ-4	Sep-88	263.71	SALLAN HAN	Oct-93	0.55	NJ-11	Mar-97	-0.47
WJ-4	Oct-88	262.79	SALLAN HAN	Nov-93	0.55	NJ-11	Apr-97	-0.14
WJ-4	Nov-88	261.9	SALLAN HAN	Dec-93	0.75	NJ-11	May-97	0.05
WJ-4	Dec-88	261.47	SALLAN HAN	Jan-94	0.76	NJ-11	Jun-97	-0.06
WJ-4	Jan-89	261.31	SALLAN HAN	Feb-94	0.8	NJ-11	Jul-97	-0.04
WJ-4	Feb-89	260.63	SALLAN HAN	Mar-94	0.81	NJ-11	Aug-97	-0.04
WJ-4	Mar-89	260.71	SALLAN HAN	Apr-94	0.77	NJ-11	Sep-97	-0.10
WJ-4	Apr-89	263.78	SALLAN HAN	May-94	0.53	NJ-11	Nov-97	-0.03
WJ-4	May-89	261.42	SALLAN HAN	Jun-94	0.36	NJ-11	Dec-97	-0.08
WJ-4	Jun-89	259.76	SALLAN HAN	Jul-94	0.32	NJ-11	Jan-98	0.58
WJ-4	Jul-89	259.42	SALLAN HAN	Aug-94	0.04	NJ-11	Feb-98	-0.04
WJ-4	Nov-89	260.84	SALLAN HAN	Sep-94	0.38	NJ-11	Mar-98	0.71
WJ-4	Dec-89	264.22	SALLAN HAN	Oct-94	0.38	NJ-11	Apr-98	0.63
WJ-4	Jan-90	264.06	SALLAN HAN	Nov-94	0.36	NJ-11	May-98	0.67
WJ-4	Feb-90	265.35	SALLAN HAN	Dec-94	0.58	NJ-11	Jun-98	0.18
WJ-4	Mar-90	264.2	SALLAN HAN	Jan-95	0.2	NJ-11	Jul-98	0.11
WJ-4	Jun-92	260.91	SALLAN HAN	Feb-95	-1.14	NJ-11	Aug-98	-0.01
WJ-4	Jul-92	259.73	SALLAN HAN	Mar-95	-0.2	NJ-11	Sep-98	0.02
WJ-4	Aug-92	260.61	SALLAN HAN	Apr-95	0.45	NJ-11	Oct-98	0.00
WJ-4	Sep-92	259.25	SALLAN HAN	May-95	0.38	NJ-11	Nov-98	-0.04
WJ-4	Oct-92	258.74	SALLAN HAN	Jun-95	0.3	NJ-11	Dec-98	0.18
WJ-4	Nov-92	258.53	SALLAN HAN	Jul-95	0.35	NJ-11	Jan-99	0.36
WJ-4	Dec-92	257.73	SALLAN HAN	Aug-95	0.65	NJ-11	Feb-99	0.61
WJ-4	Jan-93	257.47	SALLAN HAN	Sep-95	0.65	NJ-11	Mar-99	0.77
WJ-4	Feb-93	257.17	SALLAN HAN	Oct-95	0.6	NJ-11	Apr-99	0.43
WJ-4	Mar-93	261.65	SALLAN HAN	Nov-95	0.7	NJ-11	May-99	0.04
WJ-4	Apr-93	259	SALLAN HAN	Jan-96	0.95	NJ-11	Jun-99	0.06
WJ-4	May-93	258.94	SALLAN HAN	Feb-96	1.06	NJ-11	Jul-99	-0.06
WJ-4	Jun-93	257.93	SALLAN HAN	Mar-96	1.25	NJ-11	Aug-99	-0.22
WJ-4	Jul-93	257.01	SALLAN HAN	Apr-96	1.2	NJ-11	Sep-99	-0.21
WJ-4	Aug-93	256.15	SALLAN HAN	May-96	1	NJ-11	Oct-99	-0.31
WJ-4	Sep-93	255.82	SALLAN HAN	Jun-96	1	NJ-11	Nov-99	-0.31
WJ-4	Oct-93	255.61	SALLAN HAN	Jul-96	0.95	NJ-11	Dec-99	-0.27
WJ-4	Nov-93	255.56	SALLAN HAN	Aug-96	0.05	NJ-11	Jan-00	-0.21
WJ-4	Dec-93	256.71	SALLAN HAN	Sep-96	0.75	NJ-11	Feb-00	-0.32
WJ-4	Jan-94	256.55	SALLAN HAN	Oct-96	0.55	NJ-11	Mar-00	-0.39
WJ-4	Feb-94	257.12	SALLAN HAN	Nov-96	0.9	NJ-11	Apr-00	-0.51
WJ-4	Mar-94	256.66	SALLAN HAN	Dec-96	1	NJ-11	May-00	-0.68

WJ-4	Apr-94	255.92	SALLAN HAN	Jan-97	-2.7	NJ-11	Jun-00	-0.78
WJ-4	May-94	254.38	SALLAN HAN	Feb-97	1.1	NJ-11	Jul-00	-0.73
WJ-4	Jun-94	254.94	SALLAN HAN	Mar-97	1.2	NJ-11	Aug-00	-0.82
WJ-4	Jul-94	256.5	SALLAN HAN	Apr-97	1.24	NJ-11	Sep-00	-0.89
WJ-4	Aug-94	255.95	SALLAN HAN	May-97	1.41	NJ-11	Oct-00	-0.95
WJ-4	Sep-94	260.4	SALLAN HAN	Jun-97	-0.66	NJ-11	Nov-00	-0.98
WJ-4	Oct-94	262.16	SALLAN HAN	Jul-97	1.25	NJ-11	Dec-00	-0.95
WJ-4	Nov-94	260.02	SALLAN HAN	Aug-97	1.3	NJ-11	Jan-01	-0.80
WJ-4	Dec-94	258.58	SALLAN HAN	Sep-97	1.23	NJ-11	Feb-01	-0.96
WJ-4	Jan-95	258.78	SALLAN HAN	Oct-97	1.3	NJ-11	Mar-01	-0.95
WJ-4	Feb-95	257.37	SALLAN HAN	Dec-97	1.58	NJ-11	Apr-01	-1.06
WJ-4	Mar-95	261.67	SALLAN HAN	Jan-98	1.58	NJ-11	May-01	-1.31
WJ-4	May-95	253.22	SALLAN HAN	Feb-98	1.6	NJ-11	Jun-01	-1.41
WJ-4	Jun-95	253.22	SALLAN HAN	Mar-98	1.65	NJ-11	Jul-01	-2.33
WJ-4	Jul-95	253.22	SALLAN HAN	Apr-98	1.6	NJ-11	Aug-01	-2.33
WJ-4	Aug-95	253.19	SALLAN HAN	May-98	1.38	NJ-11	Jan-02	-1.37
WJ-4	Sep-95	253.31	SALLAN HAN	Jun-98	1.26	NJ-11	Feb-02	-1.34
WJ-4	Oct-95	253.31	SALLAN HAN	Jul-98	-1.2	NJ-11	Mar-02	-1.49
WJ-4	Nov-95	253.33	SALLAN HAN	Aug-98	-0.6	NJ-11	Apr-02	-1.49
WJ-4	Jan-96	263.33	SALLAN HAN	Sep-98	-2.4	NJ-11	Jun-02	-1.97
WJ-4	Feb-96	257.06	SALLAN HAN	Oct-98	1.2	NJ-11	Jun-02	-1.58
WJ-4	Mar-96	263.3	SALLAN HAN	Nov-98	1.26	NJ-11	Jul-02	-2.02
WJ-4	Apr-96	264.25	SALLAN HAN	Dec-98	1.39	NJ-11	Aug-02	-2.06
WJ-4	May-96	264.21	SALLAN HAN	Jan-99	1.4	NJ-11	Sep-02	-2.06
WJ-4	Jun-96	264.13	SALLAN HAN	Feb-99	1.55	NJ-11	Oct-02	-2.07
WJ-4	Jul-96	264.28	SALLAN HAN	Mar-99	1.6	NJ-11	Nov-02	-1.58
WJ-4	Aug-96	264.19	SALLAN HAN	Apr-99	1.41	NJ-11	Dec-02	-2.01
WJ-4	Sep-96	263.81	SALLAN HAN	May-99	1.2	NJ-11	Jan-03	-1.76
WJ-4	Oct-96	262.82	SALLAN HAN	Jun-99	1.02	NJ-11	Feb-03	-1.73
WJ-4	Nov-96	262.25	SALLAN HAN	Jul-99	0.65	NJ-11	Mar-03	-1.88
WJ-4	Dec-96	261.6	SALLAN HAN	Aug-99	-3.66	NJ-11	Apr-03	-1.90
WJ-4	Jan-97	261.77	SALLAN HAN	Sep-99	1.08	NJ-11	May-03	-2.05
WJ-4	Feb-97	263.61	SALLAN HAN	Oct-99	1	NJ-11	Jun-03	-2.23
WJ-4	Mar-97	264.53	SALLAN HAN	Nov-99	0.92	MULTAQAH	Feb-94	1.05
WJ-4	Apr-97	264.3	SALLAN HAN	Dec-99	1.08	MULTAQAH	Mar-94	1.03
WJ-4	May-97	264.52	SALLAN HAN	Feb-00	1.1	MULTAQAH	Apr-94	1.02
WJ-4	Jun-97	264.4	SALLAN HAN	Mar-00	1.03	MULTAQAH	May-94	0.86
WJ-4	Jul-97	264.32	SALLAN HAN	Apr-00	1.1	MULTAQAH	Jun-94	0.7
WJ-4	Aug-97	264.3	SALLAN HAN	May-00	0.85	MULTAQAH	Jul-94	0.67
WJ-4	Sep-97	264.4	SALLAN HAN	Jan-01	0.9	MULTAQAH	Aug-94	0.62
WJ-4	Oct-97	264.3	SALLAN HAN	Feb-01	0.87	MULTAQAH	Sep-94	0.53
WJ-4	Dec-97	264.25	SALLAN HAN	Mar-01	0.8	MULTAQAH	Oct-94	0.5
WJ-4	Jan-98	264.16	SALLAN HAN	Apr-01	0.7	MULTAQAH	Nov-94	0.52
WJ-4	Feb-98	264.22	SALLAN HAN	May-01	0.47	MULTAQAH	Dec-94	0.55
WJ-4	Mar-98	264.27	SALLAN HAN	Jun-01	0.55	MULTAQAH	Jan-95	0.56
WJ-4	Apr-98	263.96	SALLAN HAN	Aug-01	0.34	MULTAQAH	Feb-95	0.59
WJ-4	May-98	263.2	SALLAN HAN	Sep-01	0.38	MULTAQAH	Mar-95	0.69
WJ-4	Jun-98	263.92	SALLAN HAN	Oct-01	0.38	MULTAQAH	Apr-95	0.52
WJ-4	Jul-98	263.36	SALLAN HAN	Nov-01	0.38	MULTAQAH	May-95	0.41
WJ-4	Aug-98	263.85	SALLAN HAN	Dec-01	0.57	MULTAQAH	Jun-95	0.3
WJ-4	Sep-98	263.1	SALLAN HAN	Jan-02	0.59	MULTAQAH	Jul-95	0.22
WJ-4	Oct-98	263.55	SALLAN HAN	Feb-02	0.6	MULTAQAH	Aug-95	0.3
WJ-4	Nov-98	261.14	SALLAN HAN	Mar-02	0.51	MULTAQAH	Sep-95	0.24

WJ-4	Dec-98	260.6	SALLAN HAN	Apr-02	0.45	MULTAQAH	Oct-95	0.24
WJ-4	Jan-99	261.14	SALLAN HAN	May-02	0.18	MULTAQAH	Nov-95	0.35
WJ-4	Feb-99	260.29	SALLAN HAN	Jun-02	0.07	MULTAQAH	Jan-96	0.77
WJ-4	Mar-99	264.18	SALLAN HAN	Jul-02	0.04	MULTAQAH	Feb-96	0.85
WJ-4	Apr-99	261.79	SALLAN HAN	Aug-02	0.29	MULTAQAH	Mar-96	0.97
WJ-4	May-99	260.11	SALLAN HAN	Sep-02	0.24	MULTAQAH	May-96	0.97
WJ-4	Jun-99	259.47	SALLAN HAN	Oct-02	0.07	MULTAQAH	Jun-96	1.1
WJ-4	Jul-99	259.06	SALLAN HAN	Nov-02	0.42	MULTAQAH	Jun-96	0.9
WJ-4	Aug-99	258.68	SALLAN HAN	Dec-02	-0.05	MULTAQAH	Jul-96	0.83
WJ-4	Sep-99	258.3	SALLAN HAN	Jan-03	0.38	MULTAQAH	Aug-96	0.85
WJ-4	Oct-99	260.73	SALLAN HAN	Feb-03	0.4	MULTAQAH	Sep-96	0.9
WJ-4	Nov-99	259.48	SALLAN HAN	Mar-03	0.4	MULTAQAH	Oct-96	1
WJ-4	Dec-99	259.02	SALLAN HAN	Apr-03	0.2	MULTAQAH	Nov-96	1.09
WJ-4	Feb-00	258.32	SALLAN HAN	May-03	0.1	MULTAQAH	Dec-96	1.2
WJ-4	Mar-00	258.07	SALLAN HAN	Jun-03	-0.05	MULTAQAH	Jan-97	1.31
WJ-4	Apr-00	257.82	SRKM	Feb-94	-1.53	MULTAQAH	Feb-97	1.37
WJ-4	May-00	257.5	SRKM	Mar-94	-1.62	MULTAQAH	Mar-97	1.56
WJ-4	Jan-01	257.98	SRKM	Apr-94	-0.95	MULTAQAH	Apr-97	1.64
WJ-4	Feb-01	257.57	SRKM	May-94	-1.3	MULTAQAH	May-97	1.5
WJ-4	Mar-01	257.33	SRKM	Jun-94	1.13	MULTAQAH	Jun-97	1.42
WJ-4	Apr-01	257.15	SRKM	Jul-94	1.11	MULTAQAH	Jul-97	1.39
WJ-4	May-01	256.65	SRKM	Aug-94	1.06	MULTAQAH	Aug-97	1.59
WJ-4	Jun-01	255.82	SRKM	Sep-94	1.03	MULTAQAH	Sep-97	1.6
WJ-4	Aug-01	257.36	SRKM	Oct-94	-1.57	MULTAQAH	Oct-97	1.72
WJ-4	Sep-01	257.34	SRKM	Nov-94	-1.27	MULTAQAH	Dec-97	2.03
WJ-4	Oct-01	259.46	SRKM	Dec-94	-1.67	MULTAQAH	Jan-98	2.11
WJ-4	Dec-01	258.45	SRKM	Jan-95	0.98	MULTAQAH	Feb-98	2.26
WJ-4	Jan-02	-14719	SRKM	Mar-95	1.25	MULTAQAH	Mar-98	2.33
WJ-4	Feb-02	257.65	SRKM	Apr-95	-1.89	MULTAQAH	Apr-98	2.29
WJ-4	Mar-02	257.18	SRKM	May-95	-1.83	MULTAQAH	May-98	2.16
WJ-4	Apr-02	257.53	SRKM	Jun-95	-1.91	MULTAQAH	Jun-98	1.98
WJ-4	May-02	257.36	SRKM	Jul-95	-2.03	MULTAQAH	Jul-98	2.03
WJ-4	Jun-02	259.03	SRKM	Aug-95	-0.11	MULTAQAH	Aug-98	1.91
WJ-4	Jul-02	258.65	SRKM	Sep-95	0.39	MULTAQAH	Sep-98	2.04
WJ-4	Aug-02	258.8	SRKM	Oct-95	0.08	MULTAQAH	Oct-98	2.03
WJ-4	Sep-02	258.67	SRKM	Nov-95	0.46	MULTAQAH	Nov-98	2.04
WJ-4	Oct-02	258.66	SRKM	Jan-96	0.73	MULTAQAH	Dec-98	2.17
WJ-4	Nov-02	258.94	SRKM	Feb-96	3.2	MULTAQAH	Jan-99	2.27
WJ-4	Dec-02	258.26	SRKM	Mar-96	3.1	MULTAQAH	Mar-99	2.65
WJ-4	Jan-03	257.91	SRKM	Apr-96	4.14	MULTAQAH	Apr-99	2.44
OA-01	Mar-82	94.16	SRKM	May-96	3.74	MULTAQAH	May-99	2.29
OA-01	Apr-82	91.35	SRKM	Jun-96	1.76	MULTAQAH	Jun-99	1.81
OA-01	May-82	87.15	SRKM	Jul-96	1.65	MULTAQAH	Jul-99	2.08
OA-01	May-82	86.7	SRKM	Aug-96	3.79	MULTAQAH	Aug-99	1.98
OA-01	Jun-82	86.09	SRKM	Sep-96	3.29	MULTAQAH	Sep-99	2.03
OA-01	Jul-82	85.26	SRKM	Oct-96	1.27	MULTAQAH	Oct-99	1.56
OA-01	Aug-82	84.78	SRKM	Nov-96	1.35	MULTAQAH	Nov-99	1.92
OA-01	Sep-82	84.04	SRKM	Dec-96	2.32	MULTAQAH	Dec-99	1.69
OA-01	Oct-82	83.4	SRKM	Jan-97	3.56	MULTAQAH	Feb-00	1.87
OA-01	Nov-82	83.08	SRKM	Feb-97	3.47	MULTAQAH	Mar-00	1.88
OA-01	Jan-83	82.7	SRKM	Mar-97	1.64	MULTAQAH	Apr-00	1.84
OA-01	Feb-83	82.46	SRKM	Apr-97	3.96	MULTAQAH	May-00	1.67
OA-01	Mar-83	85.9	SRKM	May-97	3.83	MULTAQAH	Jan-01	1.36

OA-01	Apr-83	89.55	SRKM	Jul-97	3.37	MULTAQAH	Feb-01	1.27
OA-01	May-83	86.83	SRKM	Aug-97	2.82	HS-12	Feb-86	3.51
OA-01	Jun-83	84.85	SRKM	Sep-97	2.51	HS-12	Mar-86	3.49
OA-01	Jul-83	83.44	SRKM	Dec-97	5.27	HS-12	Apr-86	3.3
OA-01	Jul-83	83.38	SRKM	Jan-98	3.75	HS-12	Jun-86	3.12
OA-01	Sep-83	86.97	SRKM	Feb-98	3.6	HS-12	Aug-86	2.74
OA-01	Nov-83	83.9	SRKM	Mar-98	4	HS-12	Sep-86	2.61
OA-01	Jan-84	82.6	SRKM	Apr-98	5.37	HS-12	Oct-86	2.5
OA-01	Feb-84	82.25	SRKM	May-98	4.65	HS-12	Nov-86	2.38
OA-01	Apr-84	82.03	SRKM	Jun-98	4.18	HS-12	Dec-86	2.26
OA-01	May-84	81.8	SRKM	Jul-98	4.65	HS-12	Jan-87	2.18
OA-01	Sep-84	79.5	SRKM	Aug-98	2.84	HS-12	Feb-87	2.08
OA-01	Oct-84	81.4	SRKM	Sep-98	4.28	HS-12	Mar-87	2.03
OA-01	Nov-84	81.38	SRKM	Oct-98	4.35	HS-12	Apr-87	2.15
OA-01	Dec-84	79.5	SRKM	Nov-98	4.28	HS-12	May-87	2.04
OA-01	Feb-85	79.5	SRKM	Dec-98	3.38	HS-12	Jun-87	1.96
OA-01	Mar-85	79.5	SRKM	Jan-99	3.52	HS-12	Jul-87	1.87
OA-01	May-85	79.5	SRKM	Feb-99	4.05	HS-12	Aug-87	1.79
OA-01	Jul-85	79.5	SRKM	Mar-99	4.5	HS-12	Sep-87	1.74
OA-01	Aug-85	79.5	SRKM	Apr-99	3	HS-12	Oct-87	1.71
OA-01	Nov-85	79.5	SRKM	May-99	4.05	HS-12	Nov-87	1.67
OA-01	Dec-85	79.5	SRKM	Jun-99	4.01	HS-12	Dec-87	1.54
OA-01	Jan-86	79.5	SRKM	Jul-99	2.3	HS-12	Jan-88	1.81
OA-01	Mar-86	79.5	SRKM	Aug-99	2.1	HS-12	Feb-88	1.98
OA-01	Apr-86	79.5	SRKM	Sep-99	3.6	HS-12	Feb-88	2.12
OA-01	Jul-86	79.5	SRKM	Oct-99	3.52	HS-12	Mar-88	2.71
OA-01	Aug-86	79.5	SRKM	Nov-99	3.63	HS-12	Mar-88	2.72
OA-01	Sep-86	79.5	SRKM	Dec-99	1.1	HS-12	Apr-88	3.08
OA-01	Oct-86	79.5	SRKM	Feb-00	1.25	HS-12	May-88	3.32
OA-01	Nov-86	79.5	SRKM	Mar-00	1.47	HS-12	Jun-88	3.54
OA-01	Dec-86	79.5	SRKM	Apr-00	1.19	HS-12	Jul-88	3.74
OA-01	Feb-87	79.5	SRKM	May-00	0.92	HS-12	Aug-88	3.96
OA-01	Mar-87	79.5	SRKM	Jan-01	2.22	HS-12	Sep-88	4.17
OA-01	Apr-87	81.82	SRKM	Feb-01	2.09	HS-12	Oct-88	4.35
OA-01	Jun-87	84.32	SRKM	Mar-01	2.1	HS-12	Nov-88	4.54
OA-01	Jul-87	84.24	SRKM	Apr-01	-0.33	HS-12	Dec-88	4.77
OA-01	Aug-87	84.19	SRKM	May-01	-0.64	HS-12	Jan-89	4.94
OA-01	Sep-87	86.89	SRKM	Jun-01	1.51	HS-12	Feb-89	5.17
OA-01	Oct-87	83.23	SRKM	Aug-01	-0.16	HS-12	Mar-89	5.3
OA-01	Nov-87	82.58	SRKM	Sep-01	1.22	HS-12	Apr-89	5.38
OA-01	Dec-87	82.49	SRKM	Apr-02	-2.98	HS-12	May-89	5.62
OA-01	Jan-88	82.12	SRKM	Jul-02	-3.15	HS-12	Jun-89	5.66
OA-01	Feb-88	81.94	SRKM	Aug-02	-3.61	HS-12	Jul-89	5.68
OA-01	Feb-88	99.07	SRKM	Sep-02	0.55	HS-12	Aug-89	5.7
OA-01	Mar-88	100.89	SRKM	Oct-02	-2.94	HS-12	Nov-89	5.61
OA-01	Mar-88	97.93	SRKM	Nov-02	0.63	HS-12	Dec-89	5.66
OA-01	Apr-88	97.88	SRKM	Jan-03	-2.27	HS-12	Jan-90	5.75
OA-01	Jul-88	89.67	SRKM	Feb-03	0.72	HS-12	Feb-90	5.78
OA-01	Aug-88	89.16	SRKM	Mar-03	-2.28	HS-12	Mar-90	5.93
OA-01	Sep-88	89.11	SRKM	Apr-03	-3.03	HS-12	Apr-90	6.04
OA-01	Oct-88	89.06	SRKM	May-03	-0.04	HS-12	May-90	6.04
OA-01	Nov-88	87.38	SRKM	Jun-03	-3.7	HS-12	Jun-90	6.09
OA-01	Dec-88	86.23	GHJ-1	Jul-92	147.83	HS-12	Jul-90	6.07

OA-01	Jan-89	86.16	GHJ-1	Aug-92	146.65	HS-12	Aug-90	6.13
OA-01	Feb-89	86.09	GHJ-1	Nov-92	142.35	HS-12	Sep-90	6.18
OA-01	Mar-89	84.29	GHJ-1	Dec-92	141.04	HS-12	Oct-90	6.16
OA-01	Apr-89	83.44	GHJ-1	Jan-93	140.1	HS-12	Nov-90	6.2
OA-01	May-89	82.91	GHJ-1	Feb-93	139.99	HS-12	Dec-90	6.43
OA-01	Jun-89	82.35	GHJ-1	Mar-93	139.62	HS-12	Jan-91	6.08
OA-01	Jul-89	82.11	GHJ-1	Apr-93	139.92	HS-12	Feb-91	6.35
OA-01	Aug-89	82.02	GHJ-1	Jun-93	140.18	HS-12	Mar-91	6.41
OA-01	Nov-89	81.85	GHJ-1	Jul-93	139.65	HS-12	Apr-91	6.5
OA-01	Dec-89	89.03	GHJ-1	Aug-93	139.64	HS-12	May-91	6.5
OA-01	Jan-90	87.25	GHJ-1	Sep-93	135.3	HS-12	Jun-91	6.52
OA-01	Feb-90	88.77	GHJ-1	Oct-93	137.69	HS-12	Jul-91	6.54
OA-01	Mar-90	94.7	GHJ-1	Nov-93	136.76	HS-12	Aug-91	6.78
OA-01	May-90	88.58	GHJ-1	Dec-93	136.04	HS-12	Sep-91	6.45
OA-01	Jun-90	88.39	GHJ-1	Jan-94	138.77	HS-12	Oct-91	6.42
OA-01	Jul-90	88.27	GHJ-1	Feb-94	135.41	HS-12	Nov-91	6.35
OA-01	Aug-90	88.2	GHJ-1	Mar-94	134.69	HS-12	Jun-92	6.15
OA-01	Sep-90	87.39	GHJ-1	Apr-94	134	HS-12	Jul-92	6.02
OA-01	Oct-90	87.18	GHJ-1	May-94	133.75	HS-12	Aug-92	5.86
OA-01	Nov-90	86.22	GHJ-1	Jun-94	133.51	HS-12	Sep-92	5.7
OA-01	Dec-90	85.6	GHJ-1	Jul-94	136.62	HS-12	Oct-92	5.54
OA-01	Jan-91	84.77	GHJ-1	Aug-94	134.54	HS-12	Nov-92	5.37
OA-01	Feb-91	83.88	GHJ-1	Sep-94	136.92	HS-12	Dec-92	5.25
OA-01	Mar-91	83.31	GHJ-1	Oct-94	140.01	HS-12	Jan-93	5.16
OA-01	Apr-91	88.78	GHJ-1	Oct-94	140.36	HS-12	Feb-93	5.07
OA-01	May-91	86.54	GHJ-1	Nov-94	140.34	HS-12	Mar-93	4.99
OA-01	Jun-91	85.52	GHJ-1	Dec-94	140.9	HS-12	Apr-93	4.91
OA-01	Jul-91	83.76	GHJ-1	Jan-95	141.32	HS-12	May-93	4.78
OA-01	Aug-91	83.14	GHJ-1	Feb-95	140.67	HS-12	Jun-93	4.61
OA-01	Sep-91	82.03	GHJ-1	Mar-95	139.49	HS-12	Jul-93	4.47
OA-01	Oct-91	82.49	GHJ-1	Apr-95	138.24	HS-12	Sep-93	4.15
OA-01	Nov-91	82.25	GHJ-1	May-95	137.67	HS-12	Oct-93	3.99
OA-01	Jun-92	84.12	GHJ-1	Jun-95	138.14	HS-12	Nov-93	3.87
OA-01	Jul-92	83.35	GHJ-1	Jul-95	138.18	HS-12	Dec-93	3.73
OA-01	Aug-92	83.98	GHJ-1	Aug-95	138.89	HS-12	Jan-94	3.65
OA-01	Sep-92	83.68	GHJ-1	Aug-95	152.86	HS-12	Feb-94	3.6
OA-01	Oct-92	82.96	GHJ-1	Sep-95	152.68	HS-12	Mar-94	3.51
OA-01	Nov-92	82.51	GHJ-1	Oct-95	152.23	HS-12	Apr-94	3.44
OA-01	Dec-92	82.29	GHJ-1	Nov-95	151.82	HS-12	May-94	3.31
OA-01	Jan-93	82.09	GHJ-1	Dec-95	151.45	HS-12	Jun-94	3.13
OA-01	Feb-93	81.95	GHJ-1	Jan-96	152.51	HS-12	Jul-94	2.93
OA-01	Mar-93	83.55	GHJ-1	Feb-96	152.76	HS-12	Aug-94	2.76
OA-01	Apr-93	83.07	GHJ-1	Feb-96	152.62	HS-12	Sep-94	2.56
OA-01	May-93	82.7	GHJ-1	Mar-96	152.58	HS-12	Oct-94	2.39
OA-01	Jun-93	82.32	GHJ-1	Mar-96	152.25	HS-12	Nov-94	2.25
OA-01	Jul-93	82.04	GHJ-1	Mar-96	152.53	HS-12	Dec-94	2.29
OA-01	Jul-94	82.96	GHJ-1	Apr-96	152.69	HS-12	Jan-95	2.04
OA-01	Aug-94	83.49	GHJ-1	Apr-96	152.69	HS-12	Feb-95	1.93
OA-01	Sep-94	86.68	GHJ-1	May-96	152.6	HS-12	Mar-95	1.86
OA-01	Oct-94	87.61	GHJ-1	Jun-96	152.5	HS-12	Apr-95	1.79
OA-01	Nov-94	86.39	GHJ-1	Jul-96	152.51	HS-12	May-95	1.66
OA-01	Dec-94	84.8	GHJ-1	Aug-96	152.6	HS-12	Jun-95	1.54
OA-01	Jan-95	83.51	GHJ-1	Sep-96	151.61	HS-12	Jul-95	1.44

OA-01	Feb-95	82.83	GHJ-1	Oct-96	151.73	HS-12	Aug-95	1.42
OA-01	Mar-95	82.42	GHJ-1	Nov-96	150.64	HS-12	Sep-95	1.37
OA-01	Apr-95	82.32	GHJ-1	Dec-96	148.93	HS-12	Oct-95	1.39
OA-01	May-95	82.17	GHJ-1	Jan-97	147.7	HS-12	Nov-95	1.48
OA-01	Aug-95	91.84	GHJ-1	Feb-97	148.48	HS-12	Feb-96	2.19
OA-01	Sep-95	89.23	GHJ-1	Mar-97	147.26	HS-12	Mar-96	2.51
OA-01	Oct-95	87.48	GHJ-1	Apr-97	152.44	HS-12	Apr-96	2.92
OA-01	Nov-95	86.57	GHJ-1	Apr-97	152.56	HS-12	May-96	3.25
OA-01	Feb-96	96.28	GHJ-1	Apr-97	152.77	HS-12	Jun-96	3.52
OA-01	Mar-96	93.95	GHJ-1	May-97	152.67	HS-12	Jul-96	3.8
OA-01	Apr-96	98.9	GHJ-1	Jun-97	152.64	HS-12	Aug-96	3.89
OA-01	May-96	96.46	GHJ-1	Jun-97	152.67	HS-12	Sep-96	4.3
OA-01	Jun-96	94.2	GHJ-1	Jul-97	152.72	HS-12	Oct-96	4.59
OA-01	Jul-96	92.82	GHJ-1	Aug-97	152.53	HS-12	Nov-96	4.84
OA-01	Aug-96	93.18	GHJ-1	Sep-97	152.53	HS-12	Dec-96	5.08
OA-01	Sep-96	91.1	GHJ-1	Jun-99	141.59	HS-12	Jan-97	5.12
OA-01	Nov-96	88.36	GHJ-1	Jan-01	135.9	HS-12	Feb-97	5.61
OA-01	Dec-96	87.95	GHJ-1	Feb-01	132.04	HS-12	Mar-97	6.8
OA-01	Jan-97	86.58	GHJ-1	Mar-01	131.15	HS-12	Apr-97	6.04
OA-01	Feb-97	85.77	GHJ-1	Apr-01	130.99	HS-12	May-97	6.1
OA-01	Mar-97	88.48	GHJ-1	May-01	130.79	HS-12	Jun-97	6.21
OA-01	Apr-97	96.84	GHJ-1	Jun-01	130.16	HS-12	Jul-97	6.34
OA-01	May-97	94.51	GHJ-1	Aug-01	131.16	HS-12	Aug-97	6.24
OA-01	Jun-97	91.29	GHJ-1	Sep-01	130.62	HS-12	Sep-97	6.58
OA-01	Jul-97	90.27	GHJ-1	Oct-01	135.2	HS-12	Oct-97	5.17
OA-01	Aug-97	88.97	GHJ-1	Jan-02	131.78	HS-12	Jan-98	7.05
OA-01	Sep-97	88.24	GHJ-1	Feb-02	132.8	HS-12	Feb-98	7.2
OA-01	Oct-97	87.6	GHJ-1	Mar-02	130.88	HS-12	Mar-98	7.8
OA-01	Jan-98	87.7	GHJ-1	Apr-02	131.59	HS-12	Apr-98	7.86
OA-01	Feb-98	87.93	GHJ-1	May-02	136.51	HS-12	May-98	7.89
OA-01	Mar-98	88.38	GHJ-1	Jun-02	133.12	HS-12	Jun-98	7.54
OA-01	Apr-98	88.1	GHJ-1	Jul-02	131.73	HS-12	Jul-98	7.83
OA-01	May-98	87.59	GHJ-1	Aug-02	132.83	HS-12	Aug-98	7.92
OA-01	Jun-98	86.93	GHJ-1	Sep-02	133.14	HS-12	Sep-98	7.9
OA-01	Jul-98	86.37	GHJ-1	Nov-02	134.08	HS-12	Oct-98	7.77
OA-01	Aug-98	85.9	GHJ-1	Dec-02	133.64	HS-12	Nov-98	7.51
OA-01	Sep-98	85.38	GHJ-2	Jul-92	146.15	HS-12	Dec-98	7.39
OA-01	Oct-98	84.92	GHJ-2	Aug-92	144.81	HS-12	Jan-99	7.94
OA-01	Nov-98	84.34	GHJ-2	Oct-92	141.58	HS-12	Feb-99	7.73
OA-01	Dec-98	83.71	GHJ-2	Nov-92	139.77	HS-12	Mar-99	8.12
OA-01	Mar-99	84.58	GHJ-2	Dec-92	138.26	HS-12	Apr-99	8.03
OA-01	Jun-99	82.88	GHJ-2	Jan-93	137.25	HS-12	May-99	7.94
OA-01	Dec-99	81.95	GHJ-2	Feb-93	136.9	HS-12	Jun-99	8
OA-01	Mar-00	81.67	GHJ-2	Mar-93	136.62	HS-12	Jul-99	7.83
OA-01	Mar-01	82.03	GHJ-2	Apr-93	137.25	HS-12	Aug-99	7.5
JA-02	Jan-85	1.6	GHJ-2	Jun-93	138.22	HS-12	Sep-99	7.33
JA-02	Feb-85	1.54	GHJ-2	Jul-93	137.34	HS-12	Oct-99	7.2
JA-02	Mar-85	1.45	GHJ-2	Aug-93	137.3	HS-12	Nov-99	7.01
JA-02	Apr-85	1.38	GHJ-2	Sep-93	135.25	HS-12	Dec-99	7.14
JA-02	May-85	1.3	GHJ-2	Oct-93	134.45	HS-12	Feb-00	6.63
JA-02	Jun-85	1.25	GHJ-2	Nov-93	133.63	HS-12	Mar-00	6.75
JA-02	Jul-85	1.16	GHJ-2	Dec-93	133.12	HS-12	Apr-00	6.6
JA-02	Aug-85	1.09	GHJ-2	Jan-94	133	HS-12	May-00	6.27

JA-02	Sep-85	1.05	GHJ-2	Feb-94	132.82	HS-12	Jan-01	4.37
JA-02	Oct-85	1.05	GHJ-2	Mar-94	132.7	HS-12	Feb-01	4.22
JA-02	Nov-85	1	GHJ-2	Apr-94	132.75	HS-12	Apr-01	3.88
JA-02	Dec-85	1	GHJ-2	May-94	132.75	HS-12	May-01	3.6
JA-02	Jan-86	1	GHJ-2	Jun-94	132.7	HS-12	Jun-01	3.35
JA-02	Feb-86	1	GHJ-2	Jul-94	133.74	HS-12	Aug-01	2.84
JA-02	Mar-86	1	GHJ-2	Aug-94	133.2	HS-12	Sep-01	2.7
JA-02	Apr-86	0.5	GHJ-2	Sep-94	133.87	HS-12	Oct-01	2.48
JA-02	May-86	0.93	GHJ-2	Oct-94	137.44	HS-12	Nov-01	2.25
JA-02	Jun-86	0.8	GHJ-2	Oct-94	138.58	HS-12	Dec-01	2.13
JA-02	Jul-86	0.73	GHJ-2	Nov-94	138.6	HS-12	Jan-02	2.08
JA-02	Aug-86	0.7	GHJ-2	Dec-94	139.69	HS-12	Feb-02	1.95
JA-02	Sep-86	0.65	GHJ-2	Jan-95	139.43	HS-12	Mar-02	1.82
JA-02	Oct-86	1	GHJ-2	Feb-95	139.87	HS-12	Apr-02	1.7
JA-02	Nov-86	0.53	GHJ-2	Mar-95	138.56	HS-12	May-02	1.49
JA-02	Dec-86	0.4	GHJ-2	Apr-95	136.34	HS-12	Jun-02	1.34
JA-02	Jan-87	0.55	GHJ-2	May-95	136.96	HS-12	Jul-02	1.24
JA-02	Feb-87	0.57	GHJ-2	Jun-95	137.56	HS-12	Aug-02	1.09
JA-02	Mar-87	0.7	GHJ-2	Jul-95	137.57	HS-12	Sep-02	0.97
JA-02	Apr-87	1.85	GHJ-2	Aug-95	152.67	HS-12	Oct-02	0.87
JA-02	May-87	2	GHJ-2	Aug-95	152.52	HS-12	Nov-02	0.94
JA-02	Jun-87	0.9	GHJ-2	Sep-95	152.2	HS-12	Dec-02	0.85
JA-02	Jul-87	0.6	GHJ-2	Oct-95	151.76	HS-12	Jan-03	0.83
JA-02	Aug-87	0.72	GHJ-2	Nov-95	150.8	HS-12	Feb-03	0.82
JA-02	Oct-87	0.6	GHJ-2	Dec-95	150.24	HS-12	Mar-03	0.77
JA-02	Nov-87	0.48	GHJ-2	Jan-96	151.8	HS-12	Apr-03	0.75
JA-02	Dec-87	0.5	GHJ-2	Feb-96	152.64	HS-12	May-03	0.9
JA-02	Jan-88	0.5	GHJ-2	Feb-96	152.26	HS-12	Jun-03	0.66
JA-02	Feb-88	4.73	GHJ-2	Mar-96	152.12	HS-12	Jul-03	0.58
JA-02	Mar-88	2.93	GHJ-2	Mar-96	151.22	DE-2	Jan-89	9.12
JA-02	Apr-88	3	GHJ-2	Mar-96	151.96	DE-2	Feb-89	9.2
JA-02	May-88	3.11	GHJ-2	Apr-96	152.4	DE-2	Mar-89	9.18
JA-02	Jun-88	3	GHJ-2	Apr-96	152.34	DE-2	May-89	9.04
JA-02	Jul-88	3	GHJ-2	May-96	152.13	DE-2	Jun-89	8.91
JA-02	Aug-88	2.29	GHJ-2	Jun-96	151.84	DE-2	Jul-89	8.54
JA-02	Sep-88	2.22	GHJ-2	Jul-96	151.9	DE-2	Aug-89	8.33
JA-02	Oct-88	1.97	GHJ-2	Aug-96	152.19	DE-2	Nov-89	7.58
JA-02	Nov-88	1.94	GHJ-2	Sep-96	152.33	DE-2	Dec-89	7.4
JA-02	Dec-88	1.94	GHJ-2	Oct-96	150.73	DE-2	Jan-90	7.7
JA-02	Jan-89	2	GHJ-2	Nov-96	149.16	DE-2	Mar-90	8.8
JA-02	Feb-89	2	GHJ-2	Dec-96	147.29	DE-2	Apr-90	9.26
JA-02	Mar-89	2.1	GHJ-2	Jan-97	145.59	DE-2	May-90	9.3
JA-02	Apr-89	2.12	GHJ-2	Feb-97	145.98	DE-2	Jun-90	9.25
JA-02	May-89	2.1	GHJ-2	Mar-97	145.41	DE-2	Jul-90	9.2
JA-02	Jun-89	1.92	GHJ-2	Apr-97	152.06	DE-2	Aug-90	9.3
JA-02	Jul-89	1.84	GHJ-2	Apr-97	152.42	DE-2	Sep-90	9.29
JA-02	Aug-89	1.82	GHJ-2	Apr-97	152.82	DE-2	Oct-90	9.29
JA-02	Sep-89	1.79	GHJ-2	May-97	152.17	DE-2	Nov-90	9.3
JA-02	Oct-89	1.75	GHJ-2	Jun-97	152.1	DE-2	Dec-90	9.32
JA-02	Nov-89	1.72	GHJ-2	Jun-97	152.11	DE-2	Jan-91	9.27
JA-02	Dec-89	4.2	GHJ-2	Jul-97	152.25	DE-2	Feb-91	9.24
JA-02	Jan-90	2.52	GHJ-2	Aug-97	151.72	DE-2	Mar-91	9.21
JA-02	Feb-90	4.8	GHJ-2	Sep-97	151.78	DE-2	Apr-91	9.46

JA-02	Mar-90	3.34	GHJ-2	Mar-00	134.35	DE-2	May-91	9.77
JA-02	Apr-90	3	GHJ-2	Apr-00	133.84	DE-2	Jun-91	9.74
JA-02	May-90	2.79	GHJ-2	May-00	133.53	DE-2	Jul-91	9.55
JA-02	Jun-90	2.58	GHJ-2	Jan-01	136.01	DE-2	Aug-91	9.3
JA-02	Jul-90	2.77	GHJ-2	Feb-01	132.71	DE-2	Sep-91	9.05
JA-02	Aug-90	2.4	GHJ-2	Mar-01	150.12	DE-2	Oct-91	8.84
JA-02	Oct-90	2.11	GHJ-2	Apr-01	131.96	DE-2	Nov-91	8.62
JA-02	Nov-90	2.15	GHJ-2	May-01	131.77	DE-2	Jun-92	7.88
JA-02	Jan-91	2.23	GHJ-2	Jun-01	131.1	DE-2	Jul-92	7.67
JA-02	Feb-91	2.86	GHJ-2	Aug-01	131.88	DE-2	Aug-92	7.46
JA-02	Mar-91	2.3	GHJ-2	Sep-01	131.73	DE-2	Sep-92	7.21
JA-02	Apr-91	5.11	GHJ-2	Oct-01	134.53	DE-2	Oct-92	6.98
JA-02	May-91	3.2	GHJ-2	Dec-01	133.15	DE-2	Nov-92	6.71
JA-02	Jun-91	2.73	GHJ-2	Feb-02	131.64	DE-2	Dec-92	6.52
JA-02	Jul-91	2.57	GHJ-2	Mar-02	132.38	DE-2	Jan-93	6.38
JA-02	Aug-91	2.44	GHJ-2	Apr-02	132.69	DE-2	Feb-93	6.19
JA-02	Sep-91	2.36	GHJ-2	May-02	136.01	DE-2	Mar-93	6.1
JA-02	Oct-91	2.28	GHJ-2	Jun-02	133.55	DE-2	Apr-93	6
JA-02	Nov-91	2.21	GHJ-2	Jul-02	132.73	DE-2	May-93	5.87
JA-02	Dec-91	2.19	GHJ-2	Aug-02	133.43	DE-2	Jun-93	5.74
JA-02	Jan-92	2.51	GHJ-2	Sep-02	133.94	DE-2	Jul-93	5.59
JA-02	Feb-92	2.45	GHJ-2	Nov-02	134.93	DE-2	Sep-93	5.23
JA-02	Mar-92	2.47	GHJ-2	Dec-02	134.16	DE-2	Oct-93	5.07
JA-02	Apr-92	2.98	GHJ-4	Jul-92	146.98	DE-2	Nov-93	4.93
JA-02	May-92	2.59	GHJ-4	Aug-92	145.78	DE-2	Dec-93	20.97
JA-02	Jun-92	2.31	GHJ-4	Oct-92	143.03	DE-2	Jan-94	4.86
JA-02	Jul-92	2	GHJ-4	Nov-92	141.5	DE-2	Feb-94	4.53
JA-02	Aug-92	1.9	GHJ-4	Dec-92	135.24	DE-2	Mar-94	4.44
JA-02	Sep-92	1.9	GHJ-4	Jan-93	139.47	DE-2	Apr-94	4.34
JA-02	Oct-92	1.67	GHJ-4	Feb-93	139.24	DE-2	May-94	4.22
JA-02	Nov-92	1.6	GHJ-4	Mar-93	138.97	DE-2	Jun-94	4.08
JA-02	Dec-92	1.56	GHJ-4	Apr-93	139.12	DE-2	Jul-94	4.15
JA-02	Jan-93	1.57	GHJ-4	Jun-93	139.5	DE-2	Aug-94	3.77
JA-02	Mar-93	1.57	GHJ-4	Jul-93	138.92	DE-2	Sep-94	3.63
JA-02	Apr-93	1.48	GHJ-4	Aug-93	138.89	DE-2	Oct-94	3.55
JA-02	Jun-93	1.25	GHJ-4	Sep-93	137.69	DE-2	Nov-94	3.47
JA-02	Jul-93	1.09	GHJ-4	Oct-93	137.12	DE-2	Dec-94	3.37
JA-02	Aug-93	1.02	GHJ-4	Nov-93	136.38	DE-2	Jan-95	3.33
JA-02	Sep-93	0.91	GHJ-4	Dec-93	135.81	DE-2	Feb-95	3.21
JA-02	Oct-93	0.83	GHJ-4	Jan-94	138.14	DE-2	Mar-95	3.14
JA-02	Nov-93	0.78	GHJ-4	Feb-94	135.19	DE-2	Apr-95	3.09
JA-02	Dec-93	0.79	GHJ-4	Mar-94	134.35	DE-2	May-95	3.02
JA-02	Jan-94	0.86	GHJ-4	Apr-94	133.58	DE-2	Jun-95	2.94
JA-02	Feb-94	0.9	GHJ-4	May-94	133.32	DE-2	Jul-95	2.89
JA-02	Mar-94	0.85	GHJ-4	Jun-94	133.02	DE-2	Aug-95	3.92
JA-02	Apr-94	0.82	GHJ-4	Jul-94	136.3	DE-2	Sep-95	4.99
JA-02	May-94	0.72	GHJ-4	Aug-94	134.07	DE-2	Oct-95	5.45
JA-02	Jun-94	0.57	GHJ-4	Sep-94	135.27	DE-2	Nov-95	5.33
JA-02	Jul-94	0.43	GHJ-4	Oct-94	139.1	DE-2	Jan-96	9.89
JA-02	Aug-94	0.42	GHJ-4	Oct-94	139.71	DE-2	Feb-96	6.37
JA-02	Sep-94	0.34	GHJ-4	Nov-94	139.68	DE-2	Mar-96	7.15
JA-02	Oct-94	0.34	GHJ-4	Dec-94	140.09	DE-2	Apr-96	8.69
JA-02	Nov-94	0.3	GHJ-4	Jan-95	140.41	DE-2	May-96	9.45

JA-02	Jan-95	0.29	GHJ-4	Feb-95	139.83	DE-2	Jun-96	9.73
JA-02	Feb-95	0.28	GHJ-4	Mar-95	138.66	DE-2	Jul-96	9.95
JA-02	Apr-95	0.31	GHJ-4	Apr-95	137.44	DE-2	Aug-96	10
JA-02	May-95	0.21	GHJ-4	May-95	136.89	DE-2	Sep-96	10.22
JA-02	Jun-95	0.07	GHJ-4	Jun-95	137.3	DE-2	Oct-96	10.28
JA-02	Jul-95	-0.03	GHJ-4	Jul-95	137.34	DE-2	Nov-96	10.41
JA-02	Aug-95	2.2	GHJ-4	Aug-95	152.53	DE-2	Dec-96	10.56
JA-02	Oct-95	1.18	GHJ-4	Aug-95	152.1	DE-2	Jan-97	10.58
JA-02	Nov-95	0.95	GHJ-4	Sep-95	151.9	DE-2	Feb-97	10.68
JA-02	Dec-95	0.85	GHJ-4	Oct-95	151.43	DE-2	Mar-97	10.79
JA-02	Jan-96	2.91	GHJ-4	Nov-95	151.03	DE-2	Apr-97	11.27
JA-02	Feb-96	3.49	GHJ-4	Dec-95	150.64	DE-2	May-97	12.24
JA-02	Mar-96	2.25	GHJ-4	Jan-96	151.71	DE-2	Jun-97	12.7
JA-02	Apr-96	3.13	GHJ-4	Feb-96	152.01	DE-2	Jul-97	12.66
JA-02	May-96	2.54	GHJ-4	Feb-96	151.83	DE-2	Aug-97	12.52
JA-02	Jun-96	2.3	GHJ-4	Mar-96	151.8	DE-2	Sep-97	12.33
JA-02	Jul-96	2.07	GHJ-4	Mar-96	152.81	DE-2	Oct-97	12.1
JA-02	Aug-96	1.96	GHJ-4	Mar-96	152.84	DE-2	Jan-98	12.54
JA-02	Sep-96	1.5936	GHJ-4	Apr-96	151.92	DE-2	Feb-98	12.58
JA-02	Oct-96	1.9	GHJ-4	Apr-96	151.91	DE-2	Mar-98	12.8
JA-02	Nov-96	1.93	GHJ-4	May-96	151.82	DE-2	Apr-98	12.85
JA-02	Dec-96	2.01	GHJ-4	Jun-96	151.7	DE-2	May-98	12.76
JA-02	Jan-97	2.1	GHJ-4	Jul-96	151.72	DE-2	Jun-98	12.63
JA-02	Feb-97	2.38	GHJ-4	Aug-96	151.81	DE-2	Jul-98	12.39
JA-02	Mar-97	2.34	GHJ-4	Sep-96	151.54	DE-2	Aug-98	12.22
JA-02	Apr-97	5.59	GHJ-4	Oct-96	150.93	DE-2	Sep-98	12.04
JA-02	May-97	5.7	GHJ-4	Nov-96	149.83	DE-2	Oct-98	11.82
JA-02	Jun-97	4.12	GHJ-4	Dec-96	148.11	DE-2	Nov-98	11.56
JA-02	Jul-97	3.93	GHJ-4	Jan-97	146.85	DE-2	Dec-98	11.3
JA-02	Aug-97	3.32	GHJ-4	Feb-97	147.66	DE-2	May-99	10.7
JA-02	Sep-97	3.12	GHJ-4	Mar-97	146.4	DE-2	Jun-99	10.48
JA-02	Jan-98	3.69	GHJ-4	Apr-97	152.9	DE-2	Jul-99	10.2
JA-02	Feb-98	4.56	GHJ-4	Apr-97	152.73	DE-2	Aug-99	9.93
JA-02	Mar-98	4.73	GHJ-4	Apr-97	152.5	DE-2	Sep-99	9.63
JA-02	Apr-98	4.07	GHJ-4	May-97	151.89	DE-2	Oct-99	9.35
JA-02	May-98	3.84	GHJ-4	Jun-97	151.74	DE-2	Nov-99	9.02
JA-02	Jun-98	3.86	GHJ-4	Jun-97	151.89	DE-2	Dec-99	8.79
JA-02	Jul-98	3.3	GHJ-4	Jul-97	151.95	DE-2	Feb-00	8.27
JA-02	Aug-98	3.19	GHJ-4	Aug-97	151.73	DE-2	Mar-00	8.06
JA-02	Sep-98	3.07	GHJ-4	Sep-97	151.73	DE-2	Apr-00	7.85
JA-02	Oct-98	2.98	GHJ-4	Jan-99	141.41	DE-2	May-00	7.56
JA-02	Nov-98	2.92	GHJ-4	Feb-99	140.14	DE-2	Jan-01	5.58
JA-02	Jan-99	3.15	GHJ-4	Mar-99	145.84	DE-2	Feb-01	5.4
JA-02	Feb-99	3.28	GHJ-4	May-99	142.56	DE-2	Apr-01	5.09
JA-02	Mar-99	3.81	GHJ-4	Jul-99	140.05	DE-2	May-01	4.89
JA-02	Apr-99	3.34	GHJ-4	Aug-99	138.88	DE-2	Jun-01	4.7
JA-02	May-99	3.12	GHJ-4	Sep-99	137.1	DE-2	Aug-01	4.24
JA-02	Jun-99	2.87	GHJ-4	Nov-99	136.53	DE-2	Sep-01	4.1
JA-02	Jul-99	2.73	GHJ-4	Dec-99	136.34	DE-2	Oct-01	3.82
JA-02	Aug-99	2.6	GHJ-4	Feb-00	136.05	DE-2	Nov-01	3.66
JA-02	Sep-99	2.41	GHJ-4	Mar-00	135.52	DE-2	Dec-01	3.52
JA-02	Oct-99	2.41	GHJ-4	Apr-00	135.2	DE-2	Jan-02	3.45
JA-02	Nov-99	2.35	GHJ-4	May-00	134.9	DE-2	Feb-02	3.35

JA-02	Dec-99	2.29	GHJ-4	Jan-01	132.54	DE-2	Apr-02	3.2
JA-02	Feb-00	2.24	GHJ-4	Feb-01	132.21	DE-2	May-02	3.01
JA-02	Mar-00	2.18	GHJ-4	Mar-01	131.44	DE-2	Jun-02	2.93
JA-02	Apr-00	2.07	GHJ-4	Apr-01	130.96	DE-2	Jul-02	2.87
JA-02	May-00	1.94	GHJ-4	May-01	130.37	DE-2	Aug-02	2.75
JA-02	Nov-00	1.34	GHJ-4	Jun-01	130.92	DE-2	Sep-02	2.64
JA-02	Dec-00	1.25	GHJ-4	Aug-01	131.57	DE-2	Oct-02	2.54
JA-02	Jan-01	1.28	GHJ-4	Sep-01	130.72	DE-2	Nov-02	2.47
JA-02	Feb-01	1.22	GHJ-4	Oct-01	135.26	DE-2	Dec-02	2.41
JA-02	Apr-01	1.08	GHJ-4	Dec-01	132.09	DE-2	Jan-03	2.4
JA-02	May-01	0.93	GHJ-4	Jan-02	131.81	DE-2	Feb-03	2.41
JA-02	Jun-01	0.75	GHJ-4	Feb-02	131.4	DE-2	Mar-03	2.36
JA-02	Aug-01	-0.25	GHJ-4	Mar-02	130.85	DE-4	Jan-89	5.39
JA-02	Sep-01	0.4	GHJ-4	Apr-02	131.95	DE-4	May-89	5.31
JA-02	Oct-01	0.34	GHJ-4	May-02	136.69	DE-4	Jun-89	5.25
JA-02	Jan-02	0.34	GHJ-4	Jun-02	133.34	DE-4	Jul-89	5.1
JA-02	Feb-02	0.33	GHJ-4	Jul-02	132.04	DE-4	Aug-89	4.88
JA-02	Mar-02	0.3	GHJ-4	Aug-02	133.22	DE-4	Nov-89	4.44
JA-02	Apr-02	0.25	GHJ-4	Sep-02	133.42	DE-4	Dec-89	4.58
JA-02	May-02	0.06	GHJ-4	Oct-02	132.52	DE-4	Jan-90	5.08
JA-02	Jun-02	-0.03	GHJ-4	Nov-02	135.33	DE-4	Feb-90	4.99
JA-02	Jul-02	-0.09	GHJ-4	Dec-02	133.7	DE-4	Mar-90	6.13
JA-02	Aug-02	-0.17	GHJ-6	Jul-92	148.63	DE-4	Apr-90	5.96
JA-02	Sep-02	-0.22	GHJ-6	Oct-92	144.04	DE-4	May-90	5.79
JA-02	Oct-02	-0.25	GHJ-6	Nov-92	140.43	DE-4	Jun-90	5.66
JA-02	Nov-02	0.03	GHJ-6	Dec-92	139.3	DE-4	Jul-90	5.53
JA-02	Dec-02	-0.02	GHJ-6	Jan-93	139.2	DE-4	Aug-90	5.58
JA-02	Jan-03	-0.04	GHJ-6	Feb-93	139.25	DE-4	Sep-90	5.46
JA-02	Feb-03	-0.03	GHJ-6	Mar-93	139.2	DE-4	Oct-90	5.41
JA-02	Mar-03	-0.1	GHJ-6	Apr-93	139.21	DE-4	Nov-90	5.39
JA-02	Apr-03	-0.13	GHJ-6	Jun-93	139.53	DE-4	Dec-90	5.42
JA-02	May-03	-0.2	GHJ-6	Jul-93	139.25	DE-4	Jan-91	5.41
JA-02	Jun-03	-0.35	GHJ-6	Aug-93	139.23	DE-4	Feb-91	5.43
JA-03	Jan-85	24.415	GHJ-6	Sep-93	139.28	DE-4	Mar-91	5.44
JA-03	Feb-85	24.495	GHJ-6	Oct-93	135.32	DE-4	Apr-91	6.47
JA-03	Mar-85	24.615	GHJ-6	Nov-93	139.4	DE-4	May-91	6.43
JA-03	Apr-85	25.065	GHJ-6	Dec-93	139.41	DE-4	Jun-91	6.23
JA-03	May-85	25.365	GHJ-6	Jan-94	139.44	DE-4	Jul-91	5.9
JA-03	Jun-85	25.515	GHJ-6	Feb-94	139.5	DE-4	Aug-91	5.69
JA-03	Jul-85	25.915	GHJ-6	Mar-94	139.49	DE-4	Sep-91	5.27
JA-03	Aug-85	26.315	GHJ-6	Apr-94	139.54	DE-4	Oct-91	5.38
JA-03	Sep-85	26.485	GHJ-6	May-94	139.54	DE-4	Nov-91	5.23
JA-03	Oct-85	26.665	GHJ-6	Jun-94	139.6	DE-4	Jun-92	5
JA-03	Nov-85	26.815	GHJ-6	Jul-94	139.53	DE-4	Jul-92	4.8
JA-03	Dec-85	27.015	GHJ-6	Aug-94	139.49	DE-4	Aug-92	4.63
JA-03	Jan-86	27.175	GHJ-6	Sep-94	139.5	DE-4	Sep-92	4.42
JA-03	Feb-86	27.315	GHJ-6	Oct-94	139.45	DE-4	Oct-92	4.25
JA-03	Mar-86	27.445	GHJ-6	Oct-94	139.56	DE-4	Nov-92	4.05
JA-03	Apr-86	27.585	GHJ-6	Nov-94	139.58	DE-4	Dec-92	3.92
JA-03	May-86	27.715	GHJ-6	Dec-94	139.72	DE-4	Jan-93	3.8
JA-03	Jun-86	27.845	GHJ-6	Jan-95	140.1	DE-4	Feb-93	3.73
JA-03	Jul-86	28.015	GHJ-6	Feb-95	139.75	DE-4	Mar-93	3.7
JA-03	Aug-86	28.165	GHJ-6	Mar-95	139.32	DE-4	Apr-93	3.62

JA-03	Sep-86	28.235	GHJ-6	Apr-95	139.32	DE-4	May-93	3.51
JA-03	Oct-86	27.445	GHJ-6	May-95	139.14	DE-4	Jun-93	3.38
JA-03	Nov-86	28.675	GHJ-6	Jun-95	139.11	DE-4	Jul-93	3.47
JA-03	Dec-86	28.815	GHJ-6	Jul-95	139.14	DE-4	Mar-96	4.7
JA-03	Jan-87	28.835	GHJ-6	Aug-95	151.26	DE-4	Apr-96	6.01
JA-03	Feb-87	28.965	GHJ-6	Aug-95	151.79	DE-4	May-96	6.04
JA-03	Mar-87	29.025	GHJ-6	Sep-95	151.62	DE-4	Jul-96	5.9
JA-03	Apr-87	29.065	GHJ-6	Oct-95	151.25	DE-4	Aug-96	5.78
JA-03	May-87	29.115	GHJ-6	Nov-95	150.88	DE-4	Sep-96	5.85
JA-03	Jun-87	29.085	GHJ-6	Dec-95	150.51	DE-4	Oct-96	5.81
JA-03	Jul-87	30.115	GHJ-6	Jan-96	151.32	DE-4	Nov-96	5.85
JA-03	Aug-87	29.795	GHJ-6	Feb-96	151.9	DE-4	Dec-96	5.96
JA-03	Oct-87	29.035	GHJ-6	Feb-96	151.79	DE-4	Jan-97	6
JA-03	Nov-87	28.975	GHJ-6	Mar-96	151.7	DE-4	Feb-97	6.16
JA-03	Dec-87	29.015	GHJ-6	Mar-96	152.45	DE-4	Mar-97	6.38
JA-03	Jan-88	28.735	GHJ-6	Mar-96	152.39	DE-4	Apr-97	8
JA-03	Feb-88	28.015	GHJ-6	Apr-96	151.95	DE-4	May-97	8.64
JA-03	Mar-88	26.815	GHJ-6	Apr-96	151.95	DE-4	Jun-97	8.45
JA-03	Apr-88	26.695	GHJ-6	May-96	151.88	DE-4	Jul-97	8.05
JA-03	May-88	26.515	GHJ-6	Jun-96	151.78	DE-4	Aug-97	7.79
JA-03	Jun-88	26.675	GHJ-6	Jul-96	151.77	DE-4	Sep-97	7.55
JA-03	Jul-88	24.555	GHJ-6	Aug-96	151.85	DE-4	Oct-97	6.69
JA-03	Aug-88	24.275	GHJ-6	Sep-96	151.6	DE-4	Jan-98	7.98
JA-03	Sep-88	24.385	GHJ-6	Oct-96	150.9	DE-4	Feb-98	8.13
JA-03	Oct-88	23.915	GHJ-6	Nov-96	149.89	DE-4	Mar-98	8.49
JA-03	Nov-88	23.895	GHJ-6	Dec-96	148.61	DE-4	Apr-98	8.36
JA-03	Dec-88	23.635	GHJ-6	Jan-97	146.87	DE-4	May-98	8.18
JA-03	Jan-89	23.315	GHJ-6	Feb-97	146.81	DE-4	Jun-98	7.94
JA-03	Feb-89	23.175	GHJ-6	Mar-97	146.37	DE-4	Jul-98	7.69
JA-03	Mar-89	23.155	GHJ-6	Apr-97	152.29	DE-4	Aug-98	7.53
JA-03	Apr-89	23.015	GHJ-6	Apr-97	152.2	DE-4	Sep-98	7.36
JA-03	May-89	23.105	GHJ-6	Apr-97	152.09	DE-4	Oct-98	7.21
JA-03	Jun-89	22.625	GHJ-6	May-97	151.65	DE-4	Nov-98	7.01
JA-03	Jul-89	22.675	GHJ-6	Jun-97	151.58	DE-4	Dec-98	1.69
JA-03	Aug-89	23.025	GHJ-6	Jun-97	151.64	DE-4	Jan-99	6.84
JA-03	Sep-89	23.115	GHJ-6	Jul-97	151.68	DE-4	Feb-99	6.69
JA-03	Oct-89	23.205	GHJ-6	Aug-97	151.39	DE-4	Mar-99	6.96
JA-03	Nov-89	23.365	GHJ-6	Sep-97	151.35	DE-4	Apr-99	6.91
JA-03	Dec-89	23.715	GHJ-6	Jan-99	143.66	DE-4	May-99	6.79
JA-03	Jan-90	23.445	GHJ-6	Feb-99	142.73	DE-4	Jun-99	6.57
JA-03	Feb-90	23.365	GHJ-6	Mar-99	145.43	DE-4	Jul-99	6.33
JA-03	Mar-90	23.065	GHJ-6	May-99	143.6	DE-4	Aug-99	6.07
JA-03	Apr-90	23.015	GHJ-6	Jun-99	142.79	DE-4	Sep-99	5.92
JA-03	May-90	22.735	GHJ-6	Jul-99	141.55	DE-4	Oct-99	5.74
JA-03	Jun-90	22.825	GHJ-6	Aug-99	140.42	DE-4	Nov-99	5.5
JA-03	Jul-90	22.795	GHJ-6	Sep-99	136.22	DE-4	Dec-99	5.37
JA-03	Aug-90	22.515	GHJ-6	Oct-99	136.31	DE-4	Feb-00	5.07
JA-03	Oct-90	22.335	GHJ-6	Nov-99	136.2	DE-4	Mar-00	4.97
JA-03	Dec-90	22.315	GHJ-6	Dec-99	136.2	DE-4	Apr-00	4.83
JA-03	Jan-91	22.285	GHJ-6	Feb-00	136.08	DE-4	May-00	4.61
JA-03	Feb-91	22.315	GHJ-6	Mar-00	136.08	DE-4	Jun-00	4.42
JA-03	Mar-91	22.265	GHJ-6	Apr-00	136.04	DE-4	Jul-00	4.24
JA-03	Apr-91	22.215	GHJ-6	May-00	135.99	DE-4	Aug-00	4.03

JA-03	May-91	22.155	GHJ-6	Jan-01	135.74	DE-4	Sep-00	3.82
JA-03	Jun-91	22.045	GHJ-6	Feb-01	135.64	DE-4	Oct-00	3.66
JA-03	Jul-91	22.065	GHJ-6	Mar-01	135.65	DE-4	Nov-00	3.5
JA-03	Aug-91	22.105	GHJ-6	Apr-01	135.69	DE-4	Dec-00	3.38
JA-03	Sep-91	22.215	GHJ-6	May-01	135.64	DE-4	Sep-02	1.27
JA-03	Oct-91	22.345	GHJ-6	Jun-01	135.66	DE-4	Oct-02	1.2
JA-03	Nov-91	22.465	GHJ-6	Aug-01	135.75	DE-4	Nov-02	1.21
JA-03	Dec-91	22.595	GHJ-6	Sep-01	135.64	DE-4	Dec-02	1.22
JA-03	Jan-92	22.705	GHJ-6	Oct-01	135.78	DE-4	Feb-03	1.2
JA-03	Feb-92	22.845	GHJ-6	Dec-01	135.82	DE-5	Jan-89	6.49
JA-03	Mar-92	22.895	GHJ-6	Jan-02	135.87	DE-5	Feb-89	6.52
JA-03	Apr-92	23.015	GHJ-6	Feb-02	135.82	DE-5	Mar-89	6.5
JA-03	May-92	23.075	GHJ-6	Mar-02	135.74	DE-5	Apr-89	6.47
JA-03	Jun-92	23.165	GHJ-6	Apr-02	135.89	DE-5	May-89	6.32
JA-03	Jul-92	23.335	GHJ-6	May-02	136.03	DE-5	Jun-89	6.21
JA-03	Aug-92	23.525	GHJ-6	Jun-02	136.07	DE-5	Jul-89	6.03
JA-03	Sep-92	23.725	GHJ-6	Jul-02	136.02	DE-5	Aug-89	5.58
JA-03	Oct-92	23.965	GHJ-6	Aug-02	136.05	DE-5	Nov-89	4.98
JA-03	Nov-92	24.195	GHJ-6	Sep-02	136.1	DE-5	Dec-89	5.21
JA-03	Dec-92	24.395	GHJ-6	Oct-02	136.02	DE-5	Jan-90	5.84
JA-03	Jan-93	24.565	GHJ-6	Nov-02	136.12	DE-5	Feb-90	5.58
JA-03	Mar-93	24.815	GHJ-6	Dec-02	136.01	DE-5	Mar-90	7.02
JA-03	Apr-93	24.945	GHJ-6	Jan-03	135.88	DE-5	Apr-90	6.76
JA-03	Jun-93	25.175	GHJ-7	Jul-92	150.5	DE-5	May-90	6.56
JA-03	Jul-93	25.335	GHJ-7	Oct-92	150.7	DE-5	Jun-90	6.45
JA-03	Aug-93	25.495	GHJ-7	Nov-92	150.9	DE-5	Jul-90	6.33
JA-03	Sep-93	25.715	GHJ-7	Dec-92	151.1	DE-5	Aug-90	6.42
JA-03	Oct-93	25.945	GHJ-7	Jan-93	151	DE-5	Sep-90	6.32
JA-03	Nov-93	26.125	GHJ-7	Feb-93	150.95	DE-5	Oct-90	6.3
JA-03	Dec-93	26.315	GHJ-7	Jun-93	151	DE-5	Nov-90	6.3
JA-03	Jan-94	26.485	GHJ-7	Jul-93	150.5	DE-5	Dec-90	6.32
JA-03	Feb-94	26.665	GHJ-7	Aug-93	151	DE-5	Jan-91	6.3
JA-03	Mar-94	26.805	GHJ-7	Dec-93	150.95	DE-5	Feb-91	6.3
JA-03	Apr-94	26.975	GHJ-7	Jan-94	150.95	DE-5	Mar-91	6.3
JA-03	May-94	27.095	GHJ-7	Feb-94	150.95	DE-5	Apr-91	7.47
JA-03	Jun-94	27.335	GHJ-7	Mar-94	150.95	DE-5	May-91	7.14
JA-03	Jul-94	27.515	GHJ-7	Apr-94	150.95	DE-5	Jun-91	6.93
JA-03	Aug-94	27.735	GHJ-7	Jun-94	150.5	DE-5	Jul-91	6.67
JA-03	Sep-94	27.975	GHJ-7	Mar-95	151	DE-5	Aug-91	6.45
JA-03	Oct-94	28.185	GHJ-7	Apr-95	151.71	DE-5	Sep-91	6.22
JA-03	Nov-94	28.385	GHJ-7	Jul-95	151.71	DE-5	Oct-91	6.08
JA-03	Dec-94	28.565	GHJ-7	Aug-95	154.02	DE-5	Nov-91	5.89
JA-03	Jan-95	28.685	GHJ-7	Aug-95	153.05	DE-5	Jun-92	5.51
JA-03	Feb-95	28.815	GHJ-7	Sep-95	153.02	DE-5	Jul-92	5.28
JA-03	Mar-95	28.925	GHJ-7	Oct-95	153.04	DE-5	Aug-92	5.06
JA-03	Apr-95	28.965	GHJ-7	Nov-95	153.04	DE-5	Sep-92	4.85
JA-03	May-95	29.035	GHJ-7	Jan-96	153.12	DE-5	Oct-92	4.69
JA-03	Jun-95	29.125	GHJ-7	Feb-96	153.38	DE-5	Nov-92	4.44
JA-03	Jul-95	29.205	GHJ-7	Feb-96	153.17	DE-5	Dec-92	4.31
JA-03	Aug-95	29.125	GHJ-7	Mar-96	153.13	DE-5	Jan-93	4.24
JA-03	Oct-95	25.325	GHJ-7	Mar-96	155.8	DE-5	Feb-93	4.12
JA-03	Nov-95	28.015	GHJ-7	Mar-96	155.88	DE-5	Mar-93	4.07
JA-03	Dec-95	27.735	GHJ-7	Apr-96	153.33	DE-5	Apr-93	3.98

JA-03	Jan-96	27.545	GHJ-7	Apr-96	153.37	DE-5	May-93	3.86
JA-03	Feb-96	27.225	GHJ-7	May-96	153.26	DE-5	Jun-93	3.71
JA-03	Mar-96	26.615	GHJ-7	Jun-96	153.16	DE-5	Jul-93	3.56
JA-03	Apr-96	25.865	GHJ-7	Jul-96	153.18	DE-5	Sep-93	3.26
JA-03	May-96	24.995	GHJ-7	Aug-96	153.3	DE-5	Oct-93	3.15
JA-03	Jun-96	24.375	GHJ-7	Sep-96	153.05	DE-5	Nov-93	3.04
JA-03	Jul-96	23.785	GHJ-7	Oct-96	153.35	DE-5	Dec-93	2.95
JA-03	Aug-96	23.425	GHJ-7	Nov-96	152.23	DE-5	Jan-94	3.19
JA-03	Sep-96	23.065	GHJ-7	Dec-96	152.23	DE-5	Feb-94	2.84
JA-03	Oct-96	22.785	GHJ-7	Jan-97	152.23	DE-5	Mar-94	2.71
JA-03	Nov-96	22.545	GHJ-7	Feb-97	152.1	DE-5	Apr-94	2.69
JA-03	Dec-96	22.385	GHJ-7	Mar-97	152.1	DE-5	May-94	2.61
JA-03	Jan-97	22.185	GHJ-7	Apr-97	155.1	DE-5	Jun-94	2.48
JA-03	Feb-97	21.945	GHJ-7	Apr-97	154.75	DE-5	Jul-94	2.41
JA-03	Mar-97	21.835	GHJ-7	Apr-97	154.33	DE-5	Aug-94	2.32
JA-03	Apr-97	21.695	GHJ-7	May-97	153.39	DE-5	Sep-94	2.25
JA-03	May-97	21.495	GHJ-7	Jun-97	153.38	DE-5	Oct-94	2.2
JA-03	Jun-97	21.155	GHJ-7	Jun-97	153.36	DE-5	Nov-94	2.13
JA-03	Jul-97	20.835	GHJ-7	Jul-97	153.56	DE-5	Dec-94	2.05
JA-03	Aug-97	20.645	GHJ-7	Aug-97	153.49	DE-5	Jan-95	2.06
JA-03	Sep-97	20.535	GHJ-7	Sep-97	153.48	DE-5	Feb-95	1.98
JA-03	Jan-98	20.155	GHJ-7	Aug-98	152.43	DE-5	Mar-95	1.95
JA-03	Feb-98	20.035	GHJ-7	Oct-98	152.4	DE-5	Apr-95	1.91
JA-03	Mar-98	19.775	GHJ-7	Jul-99	152.4	DE-5	May-95	1.84
JA-03	Apr-98	19.635	GHJ-7	Feb-00	152.2	DE-5	Jun-95	1.79
JA-03	May-98	19.605	GHJ-7	Mar-00	152.2	DE-5	Jul-95	1.64
JA-03	Jun-98	19.525	GHJ-7	Apr-00	152.2	DE-5	Aug-95	4.62
JA-03	Jul-98	19.615	GHJ-7	May-00	152.2	DE-5	Sep-95	11.74
JA-03	Aug-98	19.695	GHJ-8	Jul-92	158.28	DE-5	Oct-95	4.28
JA-03	Jan-99	13.09	GHJ-8	Aug-92	157.78	DE-5	Nov-95	3.91
JA-03	Feb-99	12.99	GHJ-8	Oct-92	156.31	DE-5	Jan-96	12.53
JA-03	Mar-99	13.69	GHJ-8	Nov-92	155.69	DE-5	Feb-96	6.24
JA-03	Jun-99	12.79	GHJ-8	Dec-92	155.14	DE-5	Mar-96	5.82
JA-03	Jul-99	12.65	GHJ-8	Jan-93	154.62	DE-5	Apr-96	8.27
JA-03	Aug-99	12.4	GHJ-8	Feb-93	154.12	DE-5	May-96	7.6
JA-03	Nov-99	11.63	GHJ-8	Mar-93	153.67	DE-5	Jun-96	7.35
JA-03	Dec-99	11.34	GHJ-8	Apr-93	153.19	DE-5	Jul-96	7.26
JA-03	Feb-00	10.86	GHJ-8	Jun-93	152.55	DE-5	Aug-96	7.32
JA-03	Mar-00	10.68	GHJ-8	Jul-93	152.29	DE-5	Sep-96	7.4
JA-03	Apr-00	10.42	GHJ-8	Aug-93	152.27	DE-5	Oct-96	7.25
JA-03	May-00	10.18	GHJ-8	Sep-93	152.35	DE-5	Nov-96	7.29
JA-03	Nov-00	8.36	GHJ-8	Oct-93	152.03	DE-5	Dec-96	7.39
JA-03	Dec-00	8.09	GHJ-8	Nov-93	152.03	DE-5	Jan-97	7.39
JA-03	Jan-01	7.77	GHJ-8	Dec-93	152.02	DE-5	Feb-97	7.57
JA-03	Feb-01	7.51	GHJ-8	Jan-94	152.02	DE-5	Mar-97	8.15
JA-03	Apr-01	7.05	GHJ-8	Feb-94	152.02	DE-5	Apr-97	10.32
JA-03	May-01	6.81	GHJ-8	Mar-94	152.01	DE-5	May-97	10.88
JA-03	Jun-01	6.52	GHJ-8	Apr-94	152.01	DE-5	Jun-97	10.42
JA-03	Aug-01	5.05	GHJ-8	May-94	152.01	DE-5	Jul-97	9.52
JA-03	Sep-01	5.6	GHJ-8	Jun-94	152.01	DE-5	Aug-97	9.18
JA-03	Oct-01	5.42	GHJ-8	Jul-94	152	DE-5	Sep-97	8.9
JA-03	Nov-01	5.22	GHJ-8	Aug-94	152	DE-5	Oct-97	8.6
JA-03	Dec-01	5.03	GHJ-8	Sep-94	151.98	DE-5	Jan-98	9.04

JA-03	Jan-02	4.92	GHJ-8	Oct-94	151.98	DE-5	Feb-98	9.5
JA-03	Feb-02	4.78	GHJ-8	Oct-94	151.97	DE-5	Mar-98	9.84
JA-03	Mar-02	4.62	GHJ-8	Nov-94	151.94	DE-5	Apr-98	9.63
JA-03	Apr-02	4.51	GHJ-8	Dec-94	151.96	DE-5	May-98	9.31
JA-03	May-02	4.35	GHJ-8	Jan-95	151.97	DE-5	Jun-98	9.13
JA-03	Jun-02	4.25	GHJ-8	Feb-95	151.88	DE-5	Jul-98	8.84
JA-03	Jul-02	4.17	GHJ-8	Mar-95	151.97	DE-5	Aug-98	8.67
JA-03	Aug-02	4.07	GHJ-8	Apr-95	151.97	DE-5	Sep-98	8.47
JA-03	Sep-02	3.94	GHJ-8	May-95	151.95	DE-5	Oct-98	8.3
JA-03	Oct-02	3.84	GHJ-8	Jun-95	151.95	DE-5	Nov-98	8.07
JA-03	Nov-02	3.76	GHJ-8	Jul-95	151.95	DE-5	Dec-98	7.87
JA-03	Dec-02	3.71	GHJ-8	Aug-95	160.8	DE-5	May-99	7.6
JA-03	Jan-03	3.69	GHJ-8	Aug-95	160.47	DE-5	Jun-99	7.35
JA-03	Feb-03	3.69	GHJ-8	Sep-95	160.2	DE-5	Jul-99	7.09
JA-03	Mar-03	3.62	GHJ-8	Oct-95	160.53	DE-5	Aug-99	6.86
JA-03	Apr-03	3.62	GHJ-8	Nov-95	161.55	DE-5	Sep-99	6.6
JA-03	May-03	3.64	GHJ-8	Dec-95	161.75	DE-5	Oct-99	6.4
JA-03	Jun-03	3.62	GHJ-8	Jan-96	161.75	DE-5	Nov-99	6.15
JA-04	Jan-85	26.4	GHJ-8	Feb-96	162.5	DE-5	Dec-99	6
JA-04	Feb-85	26.3	GHJ-8	Feb-96	162.34	DE-5	Feb-00	5.63
JA-04	Mar-85	26.1	GHJ-8	Mar-96	162.8	DE-5	Mar-00	5.5
JA-04	Apr-85	25.3	GHJ-8	Mar-96	162.8	DE-5	Apr-00	5.33
JA-04	May-85	25.0	GHJ-8	Apr-96	162.76	DE-5	May-00	5.08
JA-04	Jun-85	24.5	GHJ-8	May-96	162.7	DE-5	Jan-01	3.66
JA-04	Jul-85	24.3	GHJ-8	Jun-96	162.61	DE-5	Feb-01	3.56
JA-04	Aug-85	24.0	GHJ-8	Jul-96	162.45	DE-5	Apr-01	3.37
JA-04	Sep-85	23.9	GHJ-8	Aug-96	162.08	DE-5	May-01	3.26
JA-04	Oct-85	23.8	GHJ-8	Sep-96	161.6	DE-5	Jun-01	3.03
JA-04	Nov-85	28.7	GHJ-8	Oct-96	161.22	DE-5	Aug-01	2.67
JA-04	Dec-85	23.6	GHJ-8	Nov-96	160.81	DE-5	Oct-01	2.39
JA-04	Jan-86	23.5	GHJ-8	Dec-96	160.31	DE-5	Nov-01	2.24
JA-04	Feb-86	23.3	GHJ-8	Jan-97	159.59	DE-5	Dec-01	2.16
JA-04	Mar-86	23.2	GHJ-8	Feb-97	159.18	DE-5	Jan-02	2.14
JA-04	Apr-86	23.0	GHJ-8	Mar-97	158.64	DE-5	Feb-02	2.07
JA-04	May-86	23.0	GHJ-8	Apr-97	162.17	DE-5	Apr-02	1.94
JA-04	Jun-86	23.0	GHJ-8	May-97	161.71	DE-5	May-02	1.79
JA-04	Jul-86	22.7	GHJ-8	Jun-97	162.36	DE-5	Jun-02	1.69
JA-04	Aug-86	22.6	GHJ-8	Jun-97	162.56	DE-5	Jul-02	1.63
JA-04	Sep-86	22.4	GHJ-8	Jul-97	162.5	DE-5	Aug-02	1.52
JA-04	Oct-86	23.2	GHJ-8	Aug-97	162.38	DE-5	Sep-02	1.42
JA-04	Nov-86	22.0	GHJ-8	Sep-97	161.9	DE-5	Oct-02	1.34
JA-04	Dec-86	21.8	GHJ-8	Aug-98	160.76	DE-5	Nov-02	1.35
JA-04	Jan-87	21.6	GHJ-8	Oct-98	159.33	DE-5	Dec-02	1.36
JA-04	Feb-87	21.7	GHJ-8	Nov-98	158.58	DE-5	Jan-03	1.34
JA-04	Mar-87	21.7	GHJ-8	Dec-98	157.74	DE-5	Feb-03	1.35
JA-04	Apr-87	21.9	GHJ-8	Jan-99	157	DE-5	Mar-03	1.29
JA-04	May-87	21.8	GHJ-8	Feb-99	156.35	DEO-10	Jan-89	0.66
JA-04	Jun-87	22.4	GHJ-8	Mar-99	159.13	DEO-10	Feb-89	0.7
JA-04	Jul-87	22.7	GHJ-8	Apr-99	158.08	DEO-10	Mar-89	0.69
JA-04	Aug-87	22.8	GHJ-8	May-99	158.03	DEO-10	Apr-89	0.7
JA-04	Oct-87	23.8	GHJ-8	Jun-99	157.69	DEO-10	May-89	0.53
JA-04	Nov-87	24.3	GHJ-8	Jul-99	156.98	DEO-10	Jun-89	0.48
JA-04	Dec-87	24.3	GHJ-8	Aug-99	156.16	DEO-10	Jul-89	0.46

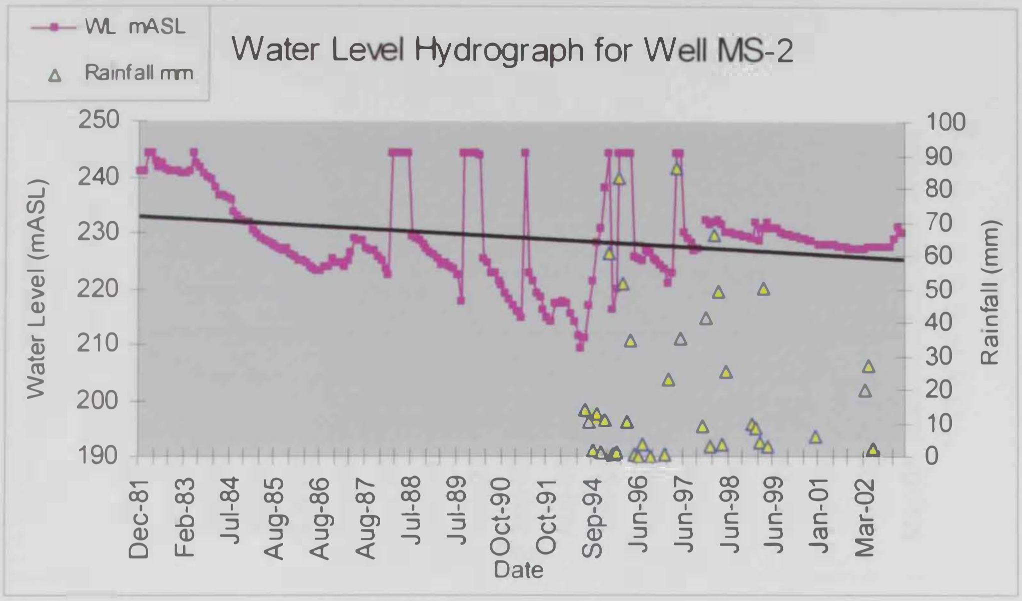
JA-04	Jan-88	25.0	GHJ-8	Sep-99	155.58	DEO-10	Aug-89	0.39
JA-04	Feb-88	25.8	GHJ-8	Oct-99	155.06	DEO-10	Nov-89	0.37
JA-04	Mar-88	26.6	GHJ-8	Nov-99	154.43	DEO-10	Dec-89	0.94
JA-04	Apr-88	26.8	GHJ-8	Dec-99	153.88	DEO-10	Jan-90	0.88
JA-04	May-88	26.8	GHJ-8	Feb-00	153.16	DEO-10	Feb-90	1.08
JA-04	Jun-88	26.7	GHJ-8	Mar-00	152.5	DEO-10	Mar-90	1.27
JA-04	Jul-88	29.1	GHJ-8	Apr-00	152.2	DEO-10	Apr-90	1.08
JA-04	Aug-88	29.9	GHJ-8	May-00	152.03	DEO-10	May-90	1.02
JA-04	Sep-88	29.5	GHJ-8	Jan-01	151.96	DEO-10	Jun-90	0.69
JA-04	Oct-88	29.7	GHJ-8	Feb-01	151.98	DEO-10	Jul-90	0.6
JA-04	Nov-88	29.8	GHJ-8	Mar-01	151.96	DEO-10	Aug-90	0.57
JA-04	Dec-88	29.8	GHJ-8	Apr-01	151.98	DEO-10	Sep-90	0.54
JA-04	Jan-89	29.7	GHJ-8	May-01	151.94	DEO-10	Oct-90	0.51
JA-04	Feb-89	29.7	GHJ-8	Jun-01	151.97	DEO-10	Nov-90	0.59
JA-04	Mar-89	29.7	GHJ-8	Aug-01	151.94	DEO-10	Dec-90	0.63
JA-04	Apr-89	30.6	GHJ-8	Sep-01	151.93	DEO-10	Jan-91	0.71
JA-04	May-89	30.5	GHJ-8	Oct-01	151.93	DEO-10	Feb-91	0.75
JA-04	Jun-89	29.3	GHJ-8	Dec-01	151.89	DEO-10	Mar-91	0.79
JA-04	Jul-89	29.2	GHJ-8	Jan-02	151.96	DEO-10	Apr-91	1.1
JA-04	Aug-89	28.9	GHJ-8	Feb-02	151.97	DEO-10	May-91	0.96
JA-04	Sep-89	28.7	GHJ-8	Mar-02	151.95	DEO-10	Jun-91	0.82
JA-04	Oct-89	28.6	GHJ-8	Apr-02	151.93	DEO-10	Jul-91	0.73
JA-04	Nov-89	28.4	GHJ-8	May-02	151.96	DEO-10	Aug-91	0.71
JA-04	Dec-89	28.2	GHJ-8	Jun-02	151.98	DEO-10	Sep-91	0.55
JA-04	Jan-90	28.1	GHJ-8	Jul-02	151.94	DEO-10	Oct-91	0.65
JA-04	Feb-90	28.1	GHJ-8	Aug-02	151.97	DEO-10	Nov-91	0.65
JA-04	Mar-90	28.3	GHJ-8	Sep-02	151.93	DEO-10	Jun-92	0.59
JA-04	Apr-90	27.7	GHJ-8	Oct-02	151.93	DEO-10	Jul-92	0.48
JA-04	May-90	29.0	GHJ-8	Nov-02	152.95	DEO-10	Aug-92	0.4
JA-04	Jun-90	29.3	GHJ-8	Dec-02	152.06	DEO-10	Sep-92	0.37
JA-04	Jul-90	29.3	GHJ-8	Jan-03	151.99	DEO-10	Oct-92	0.31
JA-04	Aug-90	29.6	MSM	Feb-94	106.05	DEO-10	Nov-92	0.3
JA-04	Oct-90	29.7	MSM	Mar-94	106.02	DEO-10	Dec-92	0.34
JA-04	Nov-90	29.7	MSM	Apr-94	105.93	DEO-10	Jan-93	0.5
JA-04	Dec-90	29.6	MSM	May-94	105.88	DEO-10	Feb-93	0.39
JA-04	Jan-91	29.6	MSM	Jun-94	105.85	DEO-10	Mar-93	0.39
JA-04	Feb-91	29.5	MSM	Jul-94	105.83	DEO-10	Apr-93	0.3
JA-04	Mar-91	29.5	MSM	Aug-94	105.84	DEO-10	May-93	0.17
JA-04	Apr-91	29.4	MSM	Sep-94	105.79	DEO-10	Jun-93	0.13
JA-04	May-91	29.4	MSM	Oct-94	105.77	DEO-10	Sep-93	-0.13
JA-04	Jun-91	29.4	MSM	Nov-94	105.86	DEO-10	Oct-93	-0.8
JA-04	Jul-91	29.3	MSM	Dec-94	105.78	DEO-10	Nov-93	-0.08
JA-04	Aug-91	29.2	MSM	Jan-95	105.75	DEO-10	Dec-93	0.02
JA-04	Sep-91	29.1	MSM	Feb-95	105.64	DEO-10	Jan-94	0.08
JA-04	Oct-91	28.9	MSM	Mar-95	105.91	DEO-10	Feb-94	0.52
JA-04	Nov-91	28.8	MSM	Apr-95	105.85	DEO-10	Mar-94	0.04
JA-04	Dec-91	28.6	MSM	May-95	105.79	DEO-10	Apr-94	0.06
JA-04	Jan-92	28.5	MSM	Jun-95	105.77	DEO-10	May-94	-0.16
JA-04	Feb-92	28.4	MSM	Jul-95	105.79	DEO-10	Jun-94	-0.21
JA-04	Mar-92	28.2	MSM	Aug-95	107.48	DEO-10	Jul-94	-0.28
JA-04	Apr-92	28.0	MSM	Sep-95	107.35	DEO-10	Aug-94	-0.29
JA-04	May-92	27.9	MSM	Oct-95	107.05	DEO-10	Sep-94	-0.3
JA-04	Jun-92	28.6	MSM	Nov-95	106.78	DEO-10	Oct-94	-0.36

JA-04	Jul-92	27.5	MSM	Jan-96	108.3	DEO-10	Nov-94	-0.3
JA-04	Aug-92	27.3	MSM	Feb-96	109.8	DEO-10	Dec-94	-0.26
JA-04	Sep-92	27.3	MSM	Mar-96	109.6	DEO-10	Jan-95	-0.24
JA-04	Oct-92	27.1	MSM	Apr-96	112.69	DEO-10	Feb-95	-0.22
JA-04	Nov-92	27.0	MSM	May-96	112.76	DEO-10	Mar-95	-0.13
JA-04	Dec-92	26.9	MSM	Jun-96	112.54	DEO-10	Apr-95	-0.24
JA-04	Jan-93	26.9	MSM	Jul-96	112.41	DEO-10	May-95	-0.48
JA-04	Feb-93	26.9	MSM	Aug-96	112.25	DEO-10	Jun-95	-0.47
JA-04	Mar-93	26.8	MSM	Sep-96	112.05	DEO-10	Jul-95	-0.65
JA-04	Apr-93	26.7	MSM	Oct-96	111.7	DEO-10	Aug-95	-0.03
JA-04	Jun-93	26.5	MSM	Nov-96	111.32	DEO-10	Sep-95	-0.02
JA-04	Jul-93	26.3	MSM	Dec-96	110.99	DEO-10	Oct-95	-0.07
JA-04	Aug-93	26.1	MSM	Jan-97	110.55	DEO-10	Nov-95	-0.07
JA-04	Sep-93	25.8	MSM	Feb-97	110.25	DEO-10	Feb-96	0.69
JA-04	Oct-93	25.5	MSM	Mar-97	109.95	DEO-10	Mar-96	0.71
JA-04	Nov-93	25.3	MSM	Apr-97	110.2	DEO-10	Apr-96	1.01
JA-04	Dec-93	25.1	MSM	May-97	111.1	DEO-10	May-96	0.68
JA-04	Jan-94	24.9	MSM	Jun-97	110.52	DEO-10	Jun-96	0.48
JA-04	Feb-94	24.8	MSM	Jul-97	110.07	DEO-10	Jul-96	0.4
JA-04	Mar-94	24.6	MSM	Aug-97	109.78	DEO-10	Aug-96	0.31
JA-04	Apr-94	24.5	MSM	Sep-97	109.73	DEO-10	Sep-96	0.3
JA-04	May-94	23.3	MSM	Oct-97	110.22	DEO-10	Oct-96	0.3
JA-04	Jun-94	24.2	MSM	Dec-97	112.36	DEO-10	Nov-96	0.4
JA-04	Jul-94	24.0	MSM	Jan-98	112.36	DEO-10	Dec-96	0.42
JA-04	Aug-94	23.9	MSM	Feb-98	112.6	DEO-10	Jan-97	0.54
JA-04	Sep-94	23.7	MSM	Mar-98	112.61	DEO-10	Feb-97	0.64
JA-04	Oct-94	23.6	MSM	Apr-98	112.47	DEO-10	Mar-97	1.15
JA-04	Nov-94	23.5	MSM	May-98	112.3	DEO-10	Apr-97	1.64
JA-04	Dec-94	23.4	MSM	Jun-98	112.22	DEO-10	May-97	1.46
JA-04	Jan-95	23.0	MSM	Jul-98	111.71	DEO-10	Jun-97	1.39
JA-04	Feb-95	23.3	MSM	Aug-98	111.49	DEO-10	Jul-97	1.03
JA-04	Mar-95	23.4	MSM	Sep-98	111.52	DEO-10	Aug-97	0.13
JA-04	Apr-95	23.4	MSM	Oct-98	110.91	DEO-10	Sep-97	0.88
JA-04	May-95	23.6	MSM	Nov-98	110.59	DEO-10	Oct-97	0.64
JA-04	Jun-95	23.7	MSM	Dec-98	110.25	DEO-10	Jan-98	1.32
JA-04	Jul-95	23.8	MSM	Mar-99	110.45	DEO-10	Feb-98	1.69
JA-04	Aug-95	23.9	MSM	Jun-99	109.34	DEO-10	Mar-98	1.63
JA-04	Oct-95	24.8	MSM	Jul-99	109	DEO-10	Apr-98	1.44
JA-04	Nov-95	25.9	MSM	Aug-99	108.65	DEO-10	May-98	1.26
JA-04	Dec-95	27.0	MSM	Nov-99	107.85	DEO-10	Aug-98	0.95
JA-04	Jan-96	27.5	MSM	Dec-99	107.72	DEO-10	Sep-98	0.9
JA-04	Feb-96	27.8	MSM	Mar-00	107.3	DEO-10	Oct-98	0.92
JA-04	Mar-96	28.2	MSM	Apr-00	107.13	DEO-10	Nov-98	0.83
JA-04	Apr-96	28.9	MSM	May-00	106.82	DEO-10	Dec-98	0.92
JA-04	May-96	29.7	MSM	Jun-00	106.23	BD88268	Jan-94	-0.18
JA-04	Jun-96	30.3	MSM	Jul-00	106.2	BD88268	Feb-94	0.95
JA-04	Jul-96	30.9	MSM	Aug-00	106.04	BD88268	Mar-94	-0.03
JA-04	Aug-96	31.2	MSM	Sep-00	106	BD88268	Apr-94	0.95
JA-04	Sep-96	31.4	MSM	Oct-00	105.8	BD88268	May-94	-0.08
JA-04	Oct-96	31.5	MSM	Nov-00	105.77	BD88268	Jun-94	0.61
JA-04	Nov-96	31.5	MSM	Dec-00	105.73	BD88268	Jul-94	0.55
JA-04	Dec-96	31.4	MSM	Jan-01	105.83	BD88268	Aug-94	0.53
JA-04	Jan-97	31.3	MSM	Feb-01	105.78	BD88268	Sep-94	0.45

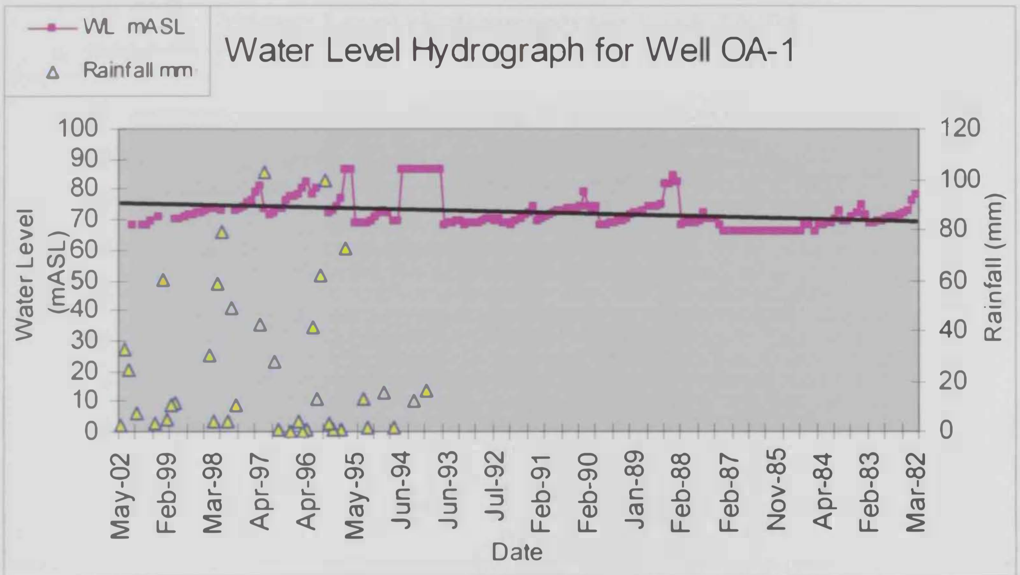
JA-04	Feb-97	31.2	MSM	Mar-01	105.7	BD88268	Oct-94	0.32
JA-04	Mar-97	31.1	MSM	Apr-01	105.8	BD88268	Nov-94	-0.42
JA-04	Apr-97	31.0	MSM	May-01	105.75	BD88268	Dec-94	-0.5
JA-04	May-97	31.0	MSM	Jun-01	105.65	BD88268	Jan-95	0.58
JA-04	Jun-97	31.3	MSM	Aug-01	105.53	BD88268	Feb-95	0.64
JA-04	Jul-97	31.6	NJ-1	Dec-89	0.2	BD88268	Mar-95	0.69
JA-04	Aug-97	31.8	NJ-1	Jan-90	0.1	BD88268	Apr-95	0.55
JA-04	Sep-97	31.8	NJ-1	Feb-90	0.32	BD88268	May-95	0.31
JA-04	Jan-98	31.8	NJ-1	Feb-90	0.14	BD88268	Jun-95	-0.74
JA-04	Feb-98	31.9	NJ-1	Mar-90	0.1	BD88268	Jul-95	-0.46
JA-04	Mar-98	32.2	NJ-1	Apr-90	0.11	BD88268	Aug-95	0.32
JA-04	Apr-98	32.2	NJ-1	Apr-90	0.24	BD88268	Sep-95	0.42
JA-04	May-98	32.1	NJ-1	May-90	0.14	BD88268	Oct-95	0.99
JA-04	Jun-98	32.1	NJ-1	Jul-90	0.13	BD88268	Nov-95	0.88
JA-04	Jul-98	31.9	NJ-1	Sep-90	0.16	BD88268	Jan-96	0.52
JA-04	Aug-98	31.8	NJ-1	Oct-90	0.06	BD88268	Feb-96	1.05
JA-04	Sep-98	31.7	NJ-1	Nov-90	0.25	BD88268	Mar-96	2
JA-04	Oct-98	31.4	NJ-1	Dec-90	-0.04	BD88268	Apr-96	1.47
JA-04	Nov-98	31.2	NJ-1	Jan-91	-0.08	BD88268	May-96	1.46
JA-04	Dec-98	30.9	NJ-1	Feb-91	-0.05	BD88268	Jun-96	0.06
JA-04	Jan-99	30.7	NJ-1	Mar-91	0.25	BD88268	Jul-96	1.46
JA-04	Feb-99	30.5	NJ-1	Apr-91	0.1	BD88268	Aug-96	0.62
JA-04	Mar-99	30.7	NJ-1	May-91	0.14	BD88268	Sep-96	1.45
JA-04	Apr-99	30.4	NJ-1	Jun-91	0.25	BD88268	Oct-96	0.66
JA-04	May-99	30.2	NJ-1	Jul-91	0.1	BD88268	Nov-96	1.5
JA-04	Jun-99	29.8	NJ-1	Aug-91	0.39	BD88268	Dec-96	0.89
JA-04	Jul-99	29.6	NJ-1	Sep-91	0.14	BD88268	Jan-97	0.9
JA-04	Aug-99	29.3	NJ-1	Oct-91	0.21	BD88268	Feb-97	1.85
JA-04	Oct-99	28.9	NJ-1	Nov-91	0.17	BD88268	Mar-97	2.18
JA-04	Nov-99	28.6	NJ-1	May-92	0.02	BD88268	Apr-97	2.7
JA-04	Dec-99	28.5	NJ-1	Jun-92	0.21	BD88268	May-97	1.86
JA-04	Jan-00	28.2	NJ-1	Jul-92	0.2	BD88268	Jun-97	1.75
JA-04	Feb-00	27.9	NJ-1	Aug-92	0.15	BD88268	Jul-97	2.43
JA-04	Mar-00	27.8	NJ-1	Sep-92	0.05	BD88268	Aug-97	2.3
JA-04	Apr-00	27.6	NJ-1	Oct-92	-0.09	BD88268	Sep-97	2.15
JA-04	May-00	27.4	NJ-1	Nov-92	0.09	BD88268	Oct-97	2.2
JA-04	Jun-00	27.1	NJ-1	Dec-92	-0.09	BD88268	Dec-97	2.75
JA-04	Jul-00	26.8	NJ-1	Jan-93	0.12	BD88268	Jan-98	1.88
JA-04	Aug-00	26.5	NJ-1	Feb-93	0.26	BD88268	Feb-98	3.04
JA-04	Sep-00	26.1	NJ-1	Mar-93	0.21	BD88268	Mar-98	3.14
JA-04	Oct-00	25.8	NJ-1	Apr-93	0.04	BD88268	May-98	2.56
JA-04	Nov-00	25.4	NJ-1	May-93	0.03	BD88268	Jun-98	1.77
JA-04	Dec-00	25.2	NJ-1	Jun-93	0.01	BD88268	Jul-98	2.33
JA-04	Jan-01	24.9	NJ-1	Jul-93	0.15	BD88268	Aug-98	2.25
JA-04	Feb-01	24.6	NJ-1	Sep-93	-0.04	BD88268	Sep-98	2.22
JA-04	Mar-01	24.5	NJ-1	Oct-93	-0.04	BD88268	Oct-98	2.2
JA-04	Apr-01	24.4	NJ-1	Nov-93	-0.2	BD88268	Nov-98	2.15
JA-04	May-01	24.3	NJ-1	Dec-93	-0.2	BD88268	Dec-98	1.7
JA-04	Jun-01	24.1	NJ-1	Jan-94	-0.25	BD88268	Jan-99	2.49
JA-04	Aug-01	23.7	NJ-1	Feb-94	0.1	BD88268	Feb-99	2.55
JA-04	Sep-01	23.8	NJ-1	Mar-94	-0.06	BD88268	Mar-99	2.77
JA-04	Oct-01	23.8	NJ-1	Apr-94	-0.15	BD88268	Apr-99	2.55
JA-04	Jun-02	23.7	NJ-1	Jun-94	0.05	BD88268	May-99	2.72

JA-04	Jul-02	23.5	NJ-1	Sep-94	-0.12	BD88268	Jun-99	0.35
JA-04	Aug-02	23.6	NJ-1	Oct-94	-0.25	BD88268	Jul-99	0.28
JA-04	Sep-02	23.6	NJ-1	Nov-94	-0.15	BD88268	Aug-99	0.93
JA-04	Oct-02	23.6	NJ-1	Dec-94	-0.25	BD88268	Sep-99	1.1
JA-04	Nov-02	23.7	NJ-1	Jan-95	-0.24	BD88268	Oct-99	1.8
JA-04	Dec-02	23.8	NJ-1	Feb-95	-0.21	BD88268	Nov-99	1.87
JA-04	Jan-03	23.8	NJ-1	Mar-95	0.05	BD88268	Dec-99	1.87
JA-04	Feb-03	23.8	NJ-1	Apr-95	-0.25	BD88268	Feb-00	-1.13
JA-04	Mar-03	23.8	NJ-1	May-95	0.04	BD88268	Mar-00	1.8
JA-04	Apr-03	23.9	NJ-1	Jun-95	-0.01	BD88268	Apr-00	-1.2
JA-04	May-03	24.2	NJ-1	Jul-95	-0.14	BD88268	May-00	-0.67
JA-04	Jun-03	24.1	NJ-1	Aug-95	0.13	BD88268	Sep-00	-0.69
JA-05	Jan-99	14.85	NJ-1	Sep-95	0.12	BD88268	Oct-00	0.3
JA-05	Feb-99	14.39	NJ-1	Oct-95	0.03	BD88268	Nov-00	0.49
JA-05	Mar-99	14.23	NJ-1	Jan-96	0.18	BD88268	Dec-00	1.03
JA-05	Apr-99	13.86	NJ-1	Feb-96	0.19	BD88268	Jan-01	1.33
JA-05	May-99	13.40	NJ-1	Mar-96	0.19	BD88268	Feb-01	1.75
JA-05	Jul-99	12.29	NJ-1	Apr-96	-0.02	BD88268	Apr-01	0.37
JA-05	Aug-99	11.72	NJ-1	May-96	-0.05	BD88268	May-01	0.95
JA-05	Jun-00	7.45	NJ-1	Jun-96	0.03	BD88268	Jun-01	0.08
JA-05	Jul-00	7.13	NJ-1	Jul-96	0.07	BD88268	Sep-01	-0.45
JA-05	Aug-00	6.82	NJ-1	Aug-96	0.08	BD88268	Oct-01	0.59
JA-05	Sep-00	6.49	NJ-1	Sep-96	0.07	BD88268	Nov-01	-0.27
JA-05	Oct-00	6.20	NJ-1	Oct-96	0.06	BD88268	Dec-01	0.59
JA-05	Nov-00	5.89	NJ-1	Nov-96	0.09	BD88268	Jan-02	0.6
JA-05	Dec-00	5.68	NJ-1	Dec-96	0.13	BD88268	Feb-02	0.3
JA-05	Jan-01	5.44	NJ-1	Jan-97	-0.08	BD88268	Apr-02	0.29
JA-05	Feb-01	5.23	NJ-1	Feb-97	-0.04	BD88268	May-02	-0.04
JA-05	Mar-01	5.02	NJ-1	Mar-97	0.19	BD88268	Jun-02	-0.73

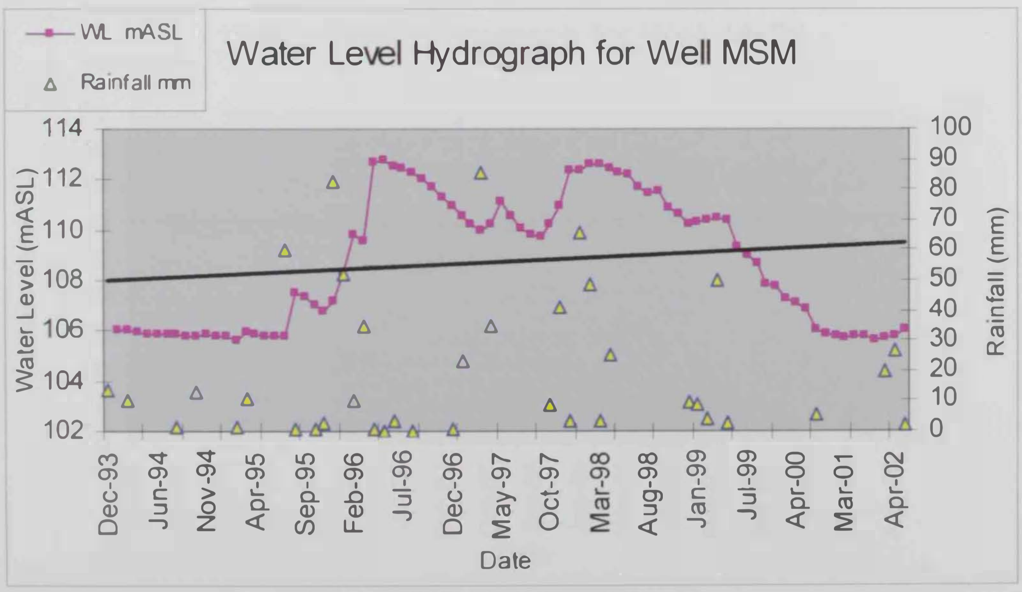
Appendix D
Hydrographs of monitoring wells



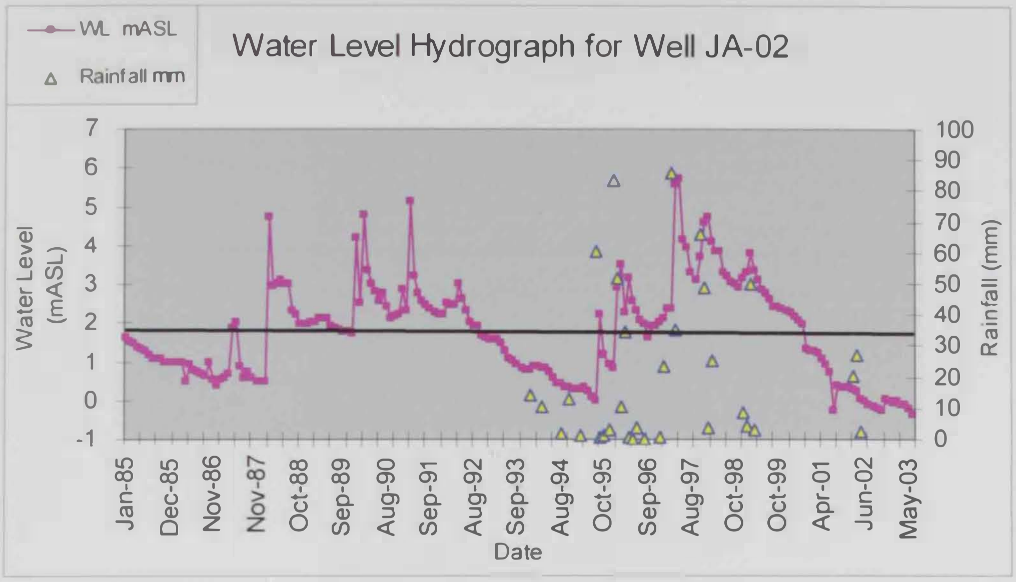
WL mASL
Rainfall mm
Water Level Hydrograph for Well MS-2
Water Level (mASL)
Rainfall (mm)
Date

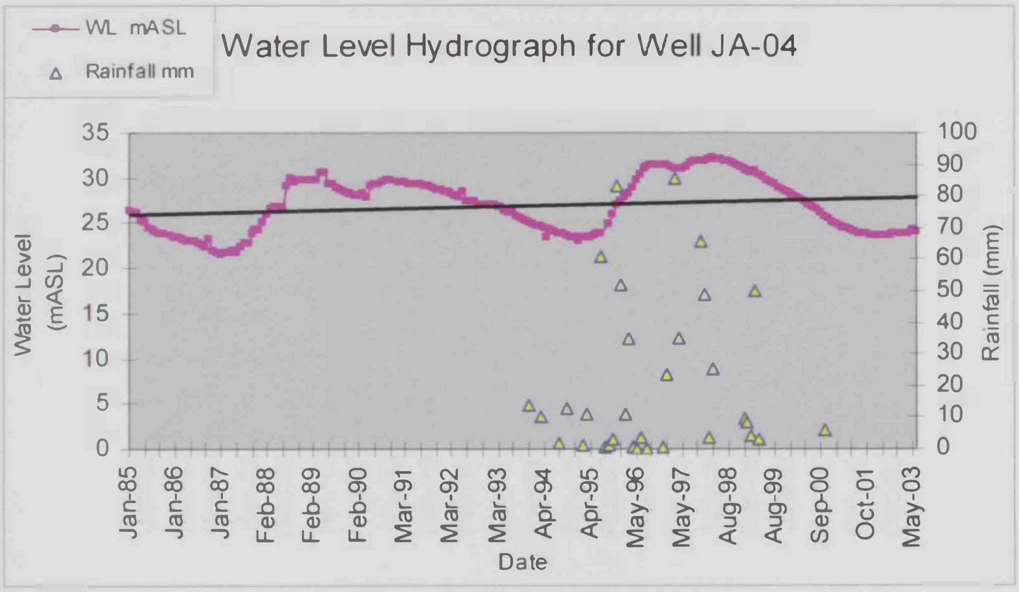


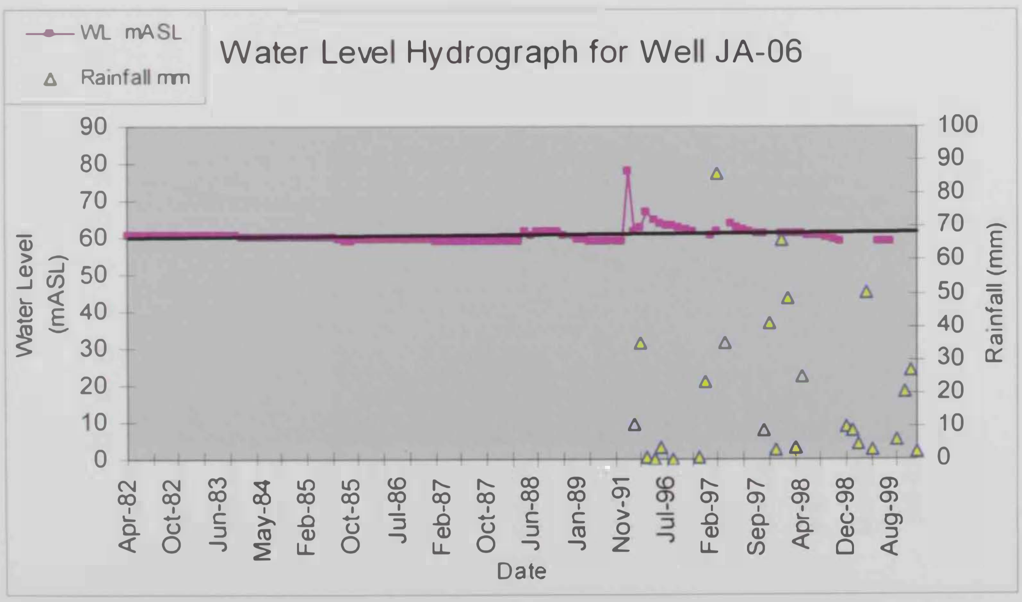
WL mASL
Rainfall mm
Water Level Hydrograph for Well OA-1
Water Level (mASL)
Rainfall (mm)
Date

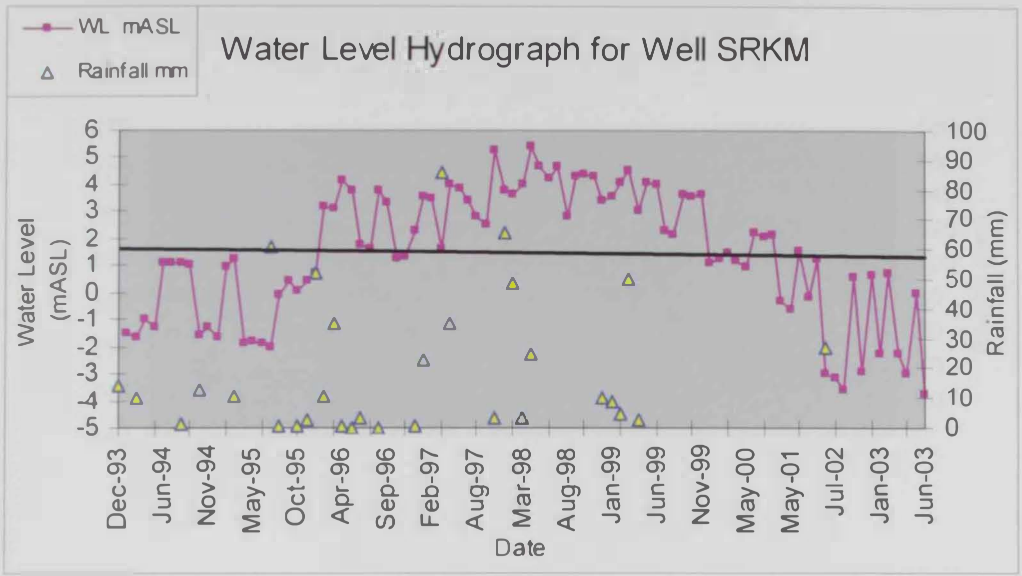


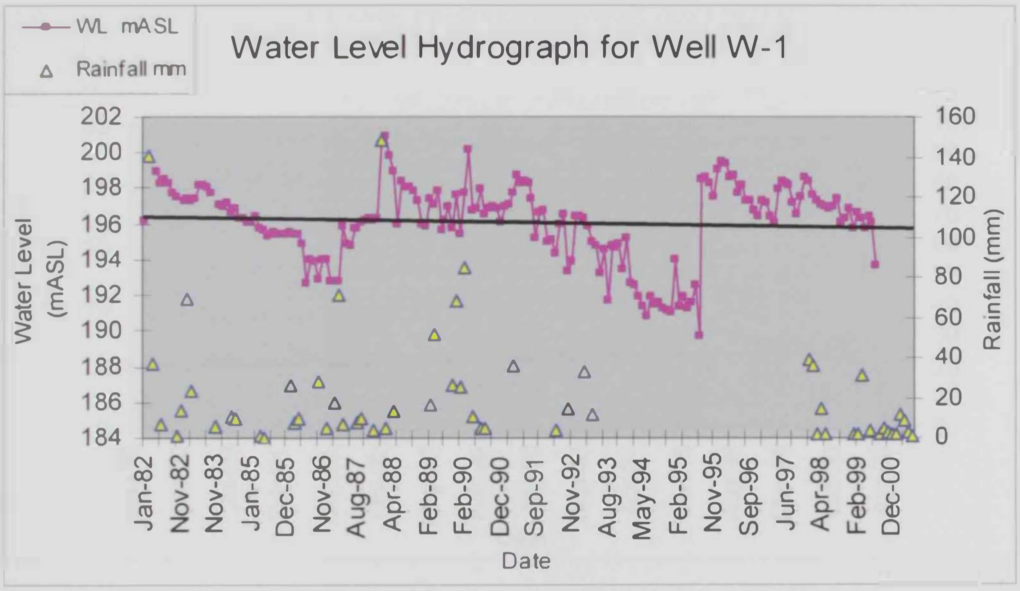
WL mASL
Rainfall mm
Water Level Hydrograph for Well MSM
Water Level (mASL)
Rainfall (mm)
Date

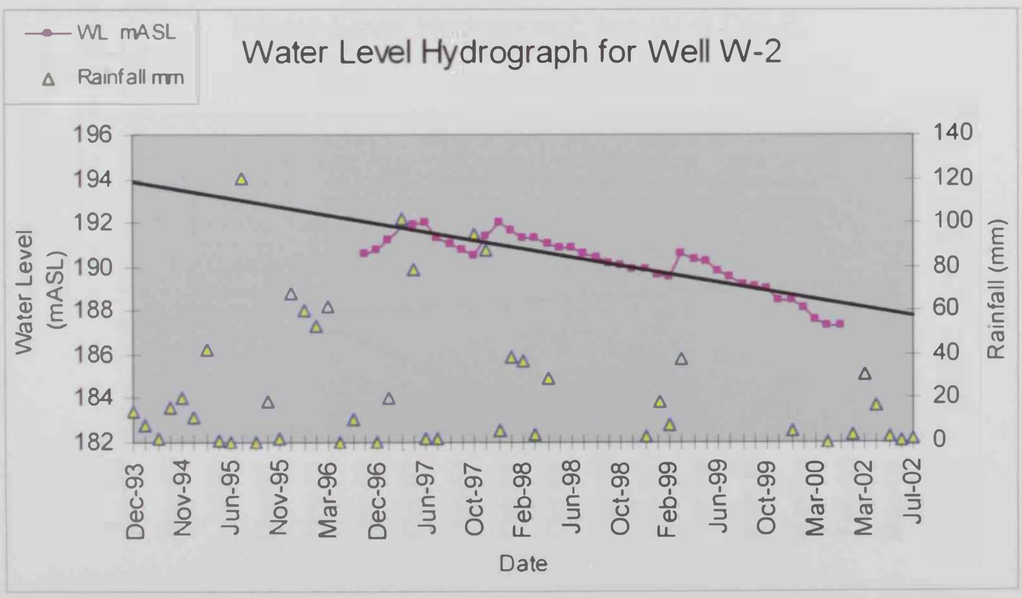

WL mASL
Rainfall mm
Water Level Hydrograph for Well JA-02
Water Level (mASL)
Rainfall (mm)
Date
Jan-85
Dec-85
Nov-86
Nov-87
Oct-88
Sep-89
Aug-90
Sep-91
Aug-92
Sep-93
Aug-94
Oct-95
Sep-96
Aug-97
Oct-98
Oct-99
Apr-01
Jun-02
May-03

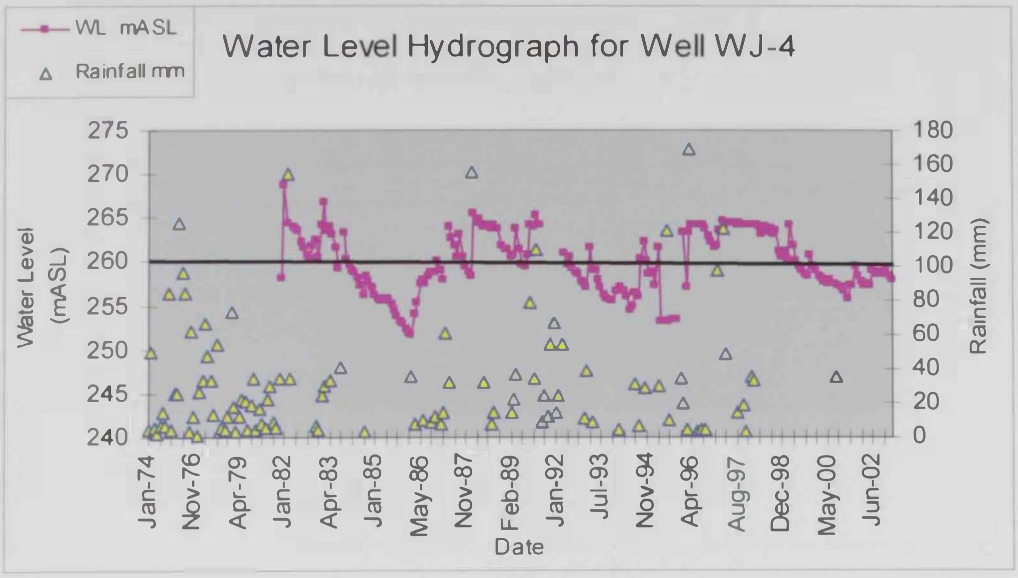

WL mASL
Rainfall mm
Water Level Hydrograph for Well JA-04
Water Level (mASL)
Rainfall (mm)
Date
Jan-85
Jan-86
Jan-87
Feb-88
Feb-89
Feb-90
Mar-91
Mar-92
Mar-93
Apr-94
Apr-95
May-96
May-97
Aug-98
Aug-99
Sep-00
Oct-01
May-03

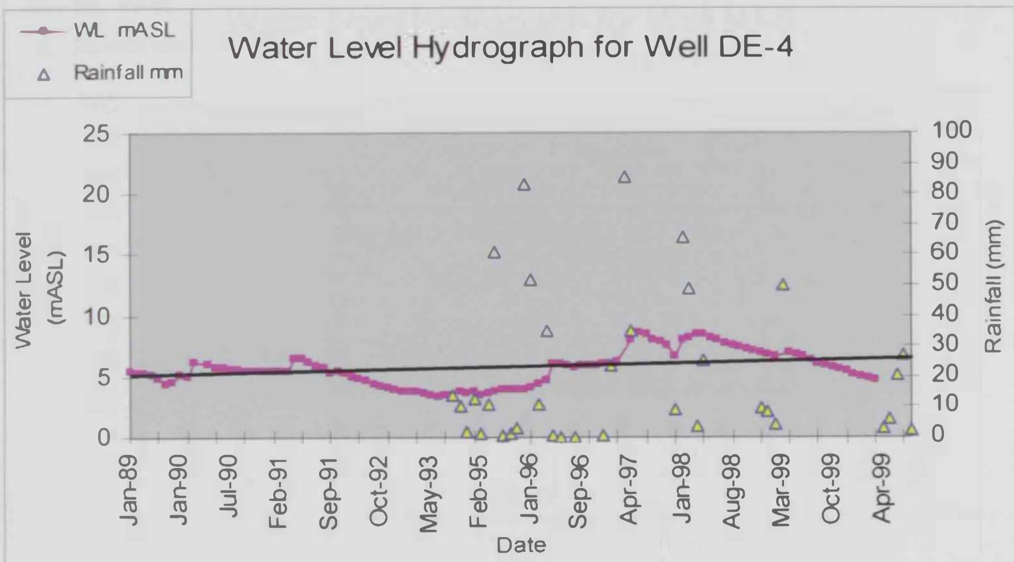

WL mASL
Rainfall mm
Water Level Hydrograph for Well JA-06
Water Level (mASL)
Rainfall (mm)
Date
Apr-82
Oct-82
Jun-83
May-84
Feb-85
Oct-85
Jul-86
Feb-87
Oct-87
Jun-88
Jan-89
Nov-91
Jul-96
Feb-97
Sep-97
Apr-98
Dec-98
Aug-99

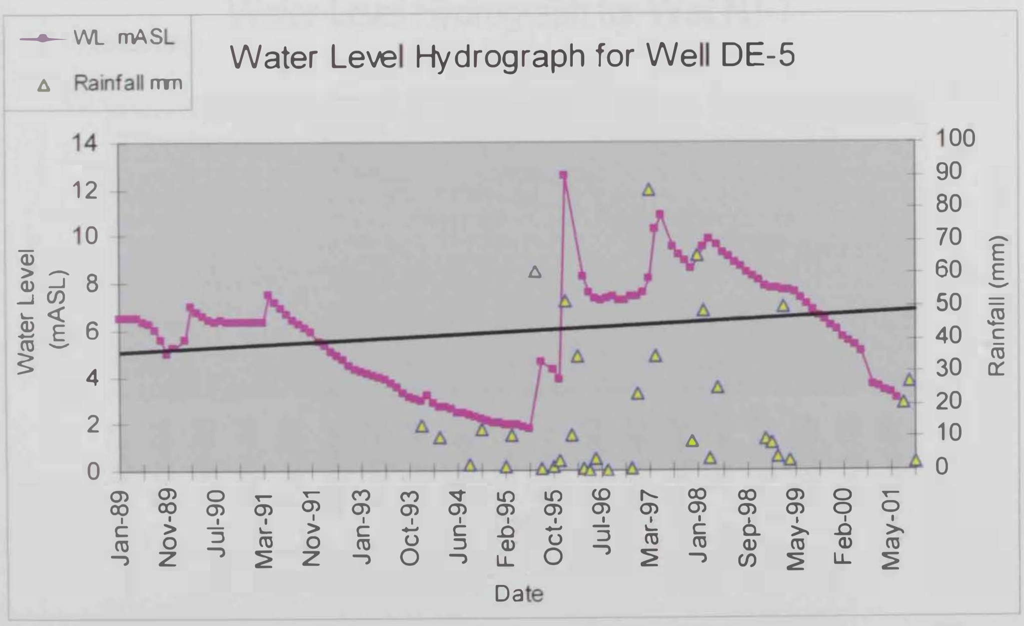

WL mASL
Rainfall mm
Water Level Hydrograph for Well SRKM
Water Level (mASL)
Rainfall (mm)
Date
Dec-93
Jun-94
Nov-94
May-95
Oct-95
Apr-96
Sep-96
Feb-97
Aug-97
Mar-98
Aug-98
Jan-99
Jun-99
Nov-99
May-00
May-01
Jul-02
Jan-03
Jun-03

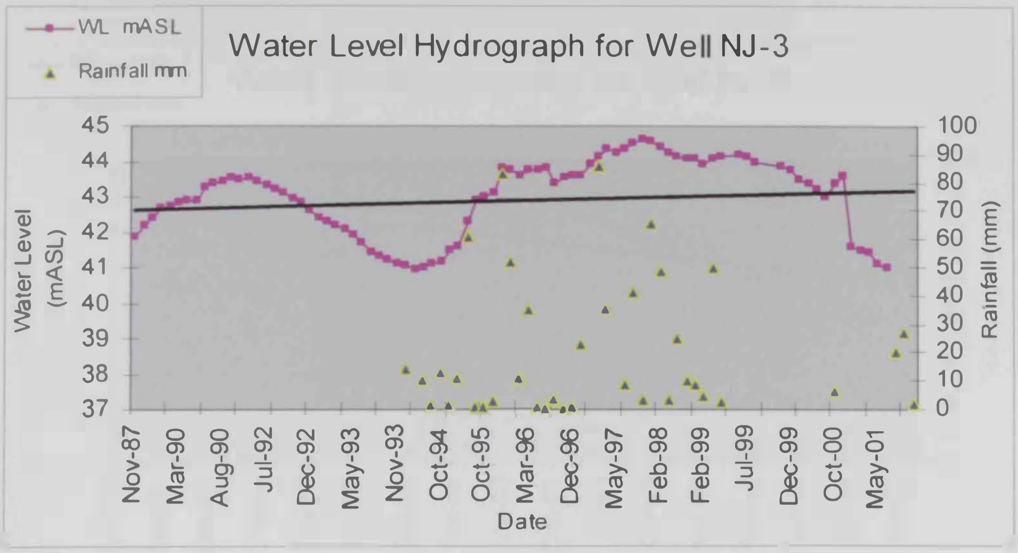

WL mASL
Rainfall mm
Water Level Hydrograph for Well W-1
Water Level (mASL)
Rainfall (mm)
Date
Jan-82
Nov-82
Nov-83
Jan-85
Dec-85
Nov-86
Aug-87
Apr-88
Feb-89
Feb-90
Dec-90
Sep-91
Nov-92
Aug-93
May-94
Feb-95
Nov-95
Sep-96
Jun-97
Apr-98
Feb-99
Dec-00

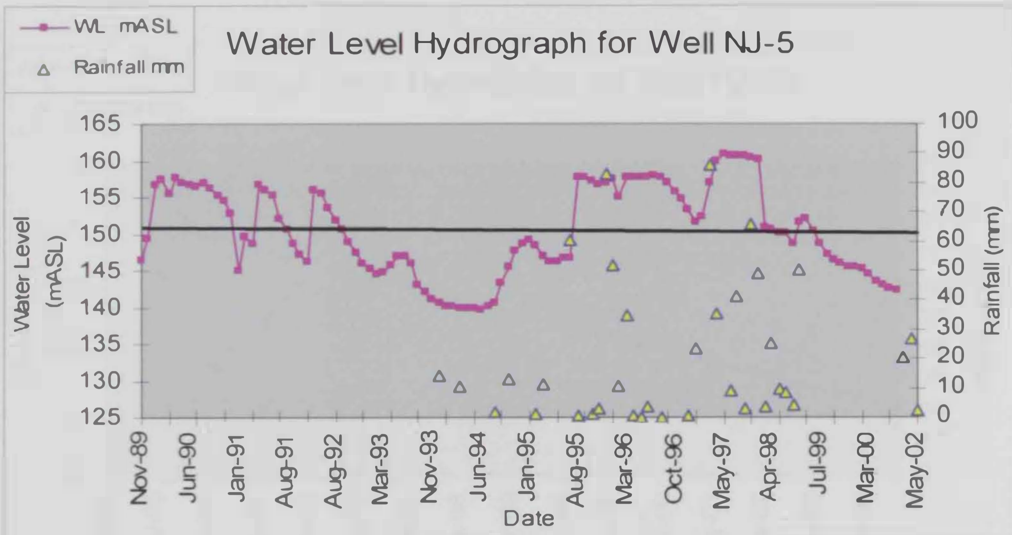

WL mASL
Rainfall mm
Water Level Hydrograph for Well W-2
Water Level (mASL)
Rainfall (mm)
Date
Dec-93
Nov-94
Jun-95
Nov-95
Mar-96
Dec-96
Jun-97
Oct-97
Feb-98
Jun-98
Oct-98
Feb-99
Jun-99
Oct-99
Mar-00
Mar-02
Jul-02

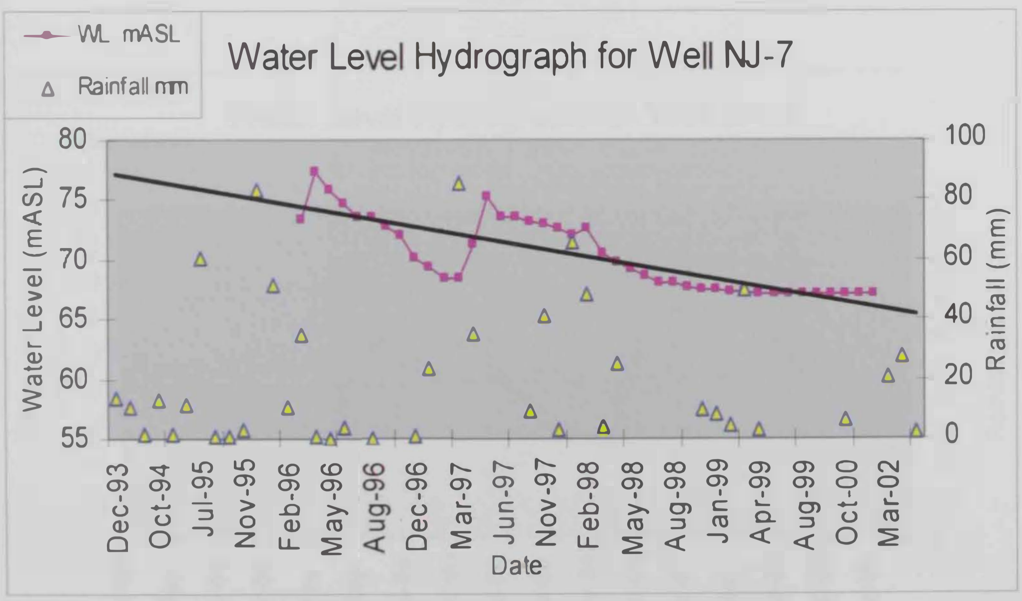

Water Level Hydrograph for Well WJ-4
WL mASL
Rainfall mm
Water Level (mASL)
Rainfall (mm)
Date
275
270
265
260
255
250
245
240
180
160
140
120
100
80
60
40
20
0
Jan-74
Nov-76
Apr-79
Jan-82
Apr-83
Jan-85
May-86
Nov-87
Feb-89
Jan-92
Jul-93
Nov-94
Apr-96
Aug-97
Dec-98
May-00
Jun-02

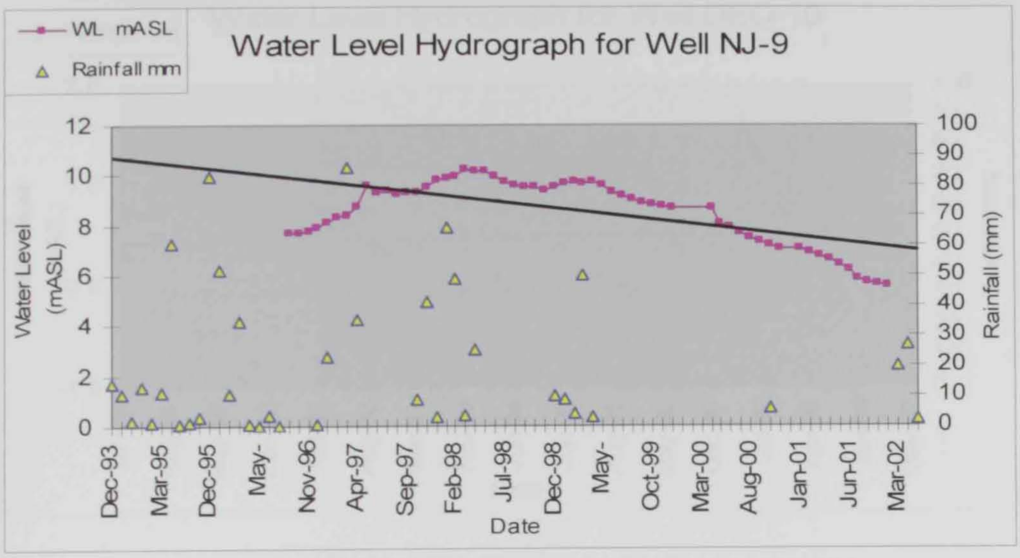

Water Level Hydrograph for Well DE-4
WL mASL
Rainfall mm
Water Level (mASL)
Rainfall (mm)
Date
25
20
15
10
5
0
100
90
80
70
60
50
40
30
20
10
0
Jan-89
Jan-90
Jul-90
Feb-91
Sep-91
Oct-92
May-93
Feb-95
Jan-96
Sep-96
Apr-97
Jan-98
Aug-98
Mar-99
Oct-99
Apr-99

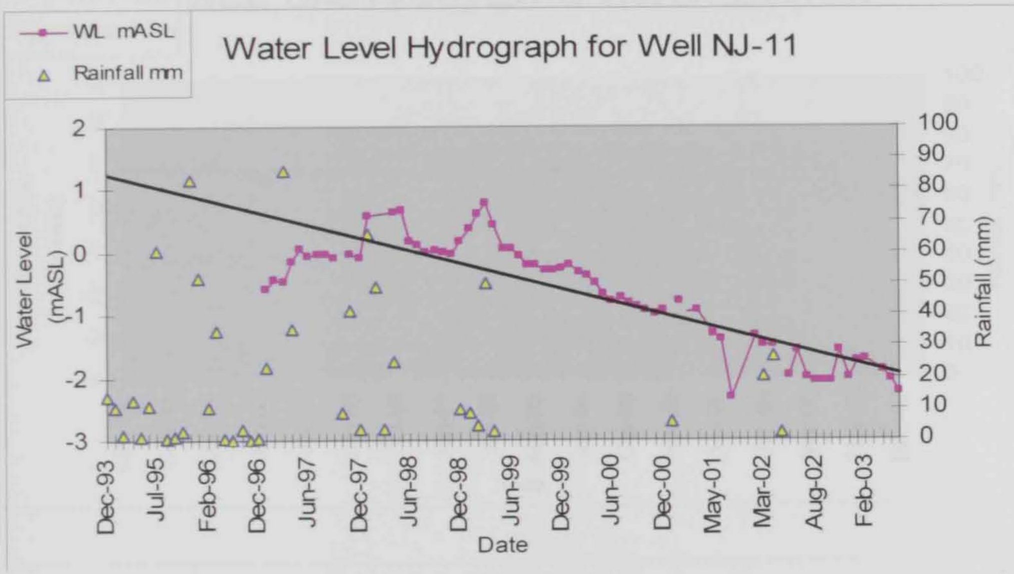

Water Level Hydrograph for Well DE-5
WL mASL
Rainfall mm
Water Level (mASL)
Rainfall (mm)
Date
14
12
10
8
6
4
2
0
100
90
80
70
60
50
40
30
20
10
0
Jan-89
Nov-89
Jul-90
Mar-91
Nov-91
Jan-93
Oct-93
Jun-94
Feb-95
Oct-95
Jul-96
Mar-97
Jan-98
Sep-98
May-99
Feb-00
May-01

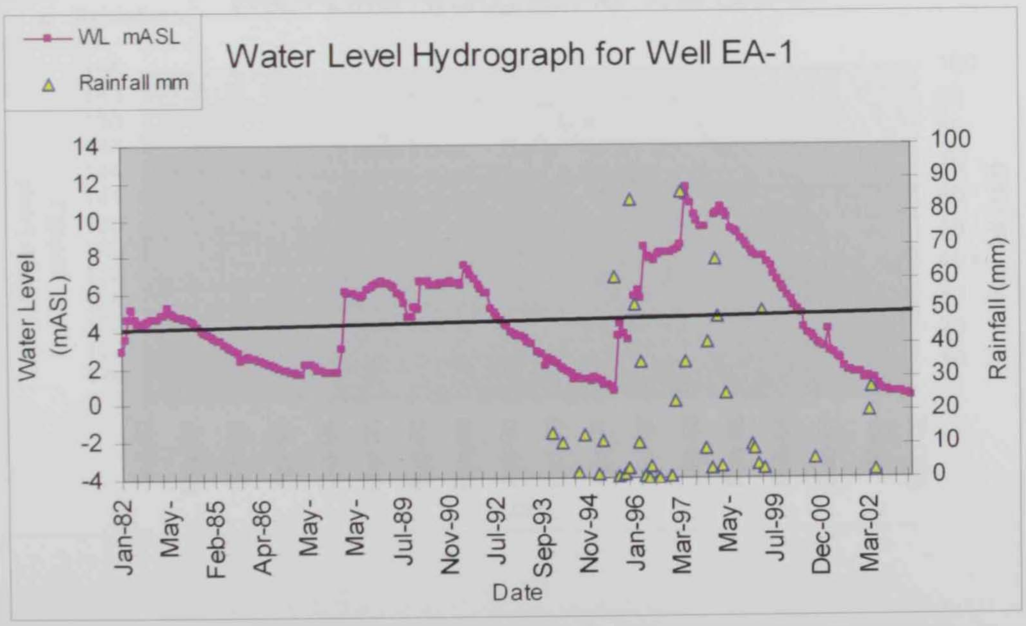

WL mASL
Rainfall mm
Water Level Hydrograph for Well NJ-3
Water Level (mASL)
Rainfall (mm)
Date

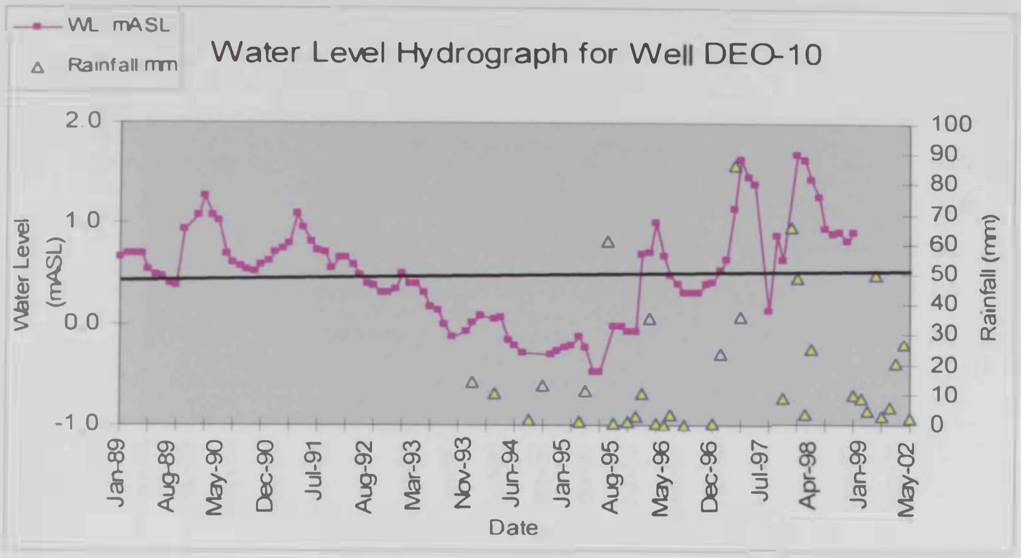

WL mASL
Rainfall mm
Water Level Hydrograph for Well NJ-5
Water Level (mASL)
Rainfall (mm)
Date

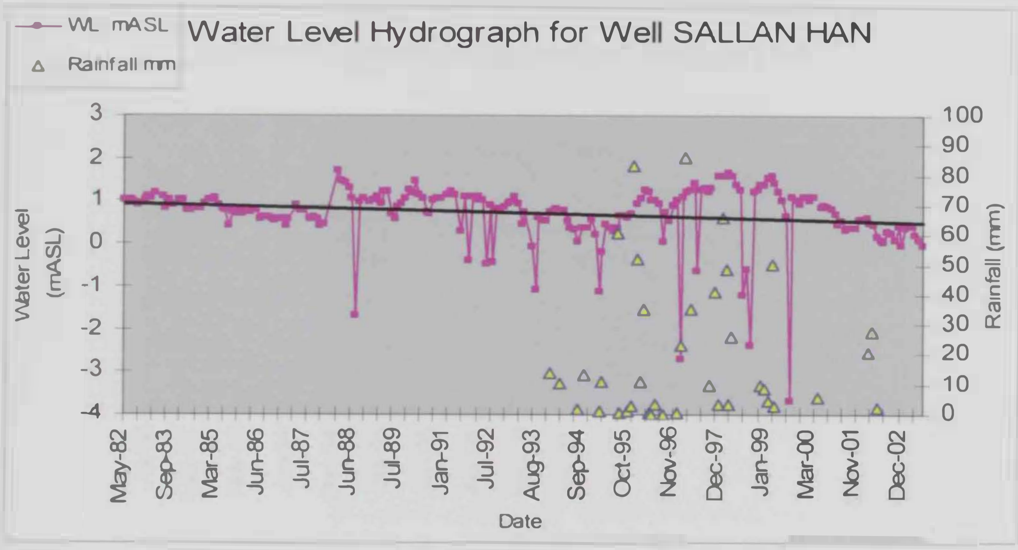

WL mASL
Rainfall mm
Water Level Hydrograph for Well NJ-7
Water Level (mASL)
Rainfall (mm)
Date

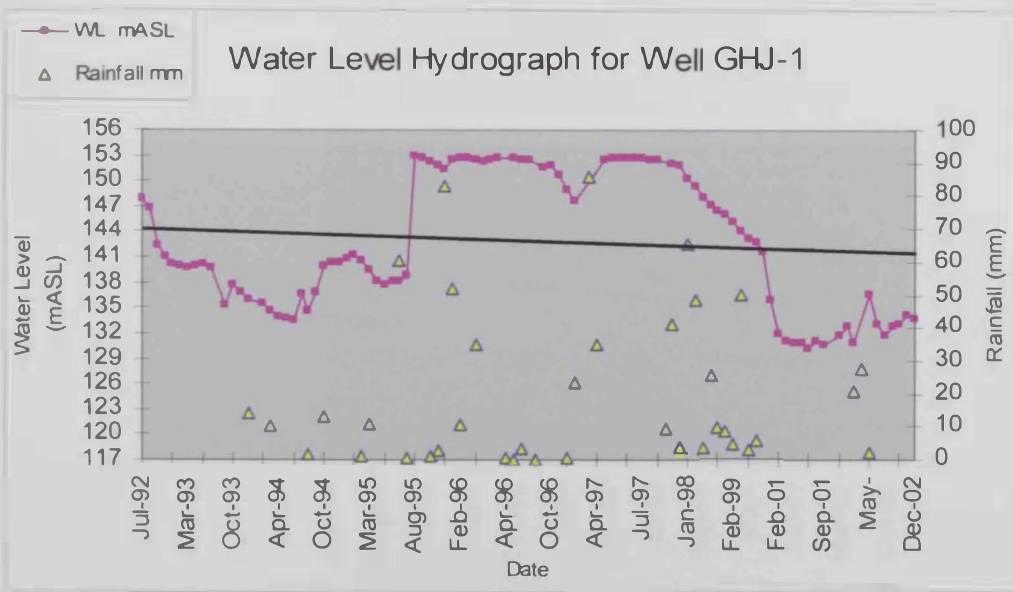

WL mASL
Rainfall mm
Water Level Hydrograph for Well NJ-9
Water Level (mASL)
Rainfall (mm)
Date
Dec-93
Mar-95
Dec-95
May-
Nov-96
Apr-97
Sep-97
Feb-98
Jul-98
Dec-98
May-
Oct-99
Mar-00
Aug-00
Jan-01
Jun-01
Mar-02

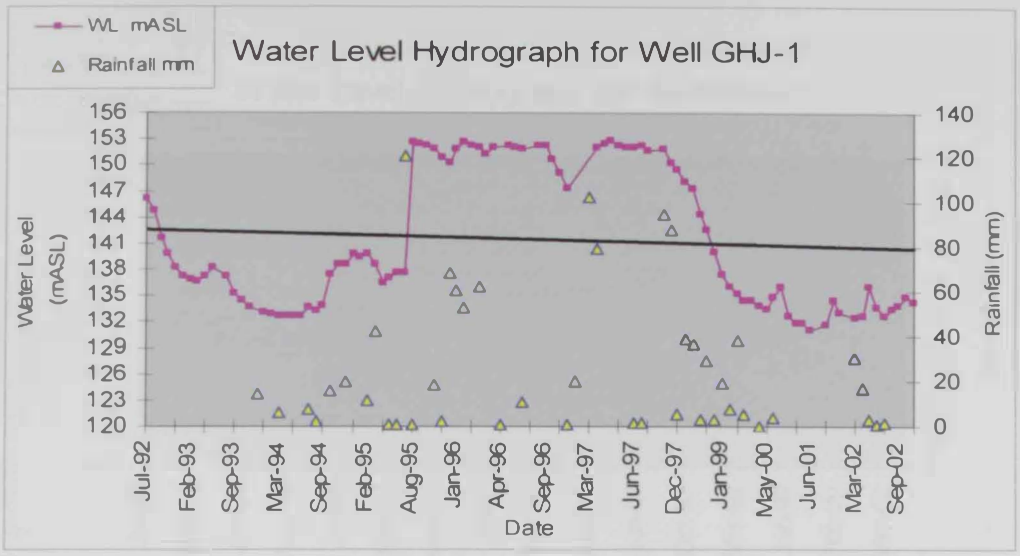

WL mASL
Rainfall mm
Water Level Hydrograph for Well NJ-11
Water Level (mASL)
Rainfall (mm)
Date
Dec-93
Jul-95
Feb-96
Dec-96
Jun-97
Dec-97
Jun-98
Dec-98
Jun-99
Dec-99
Jun-00
Dec-00
May-01
Mar-02
Aug-02
Feb-03

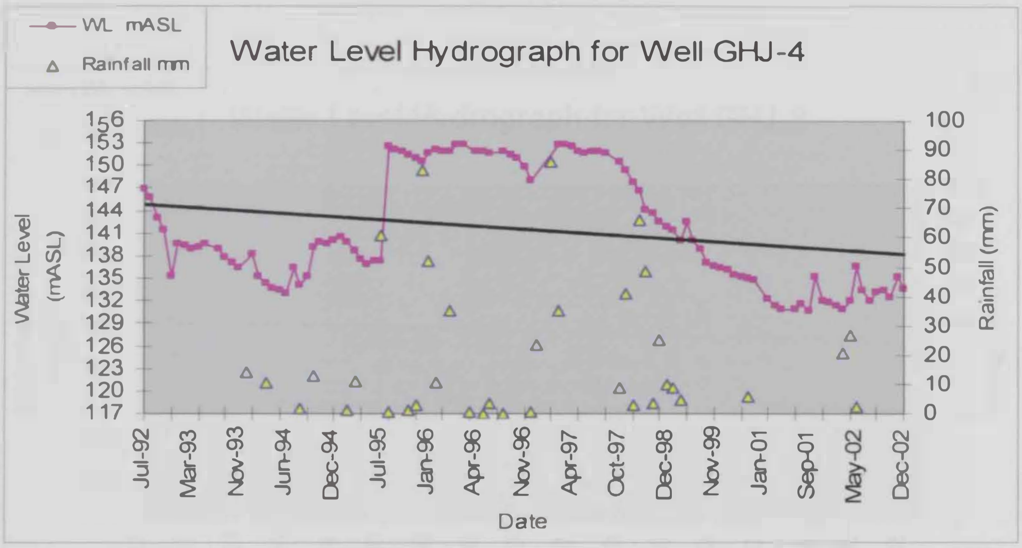

WL mASL
Rainfall mm
Water Level Hydrograph for Well EA-1
Water Level (mASL)
Rainfall (mm)
Date
Jan-82
May-
Feb-85
Apr-86
May-
May-
Jul-89
Nov-90
Jul-92
Sep-93
Nov-94
Jan-96
Mar-97
May-
Jul-99
Dec-00
Mar-02

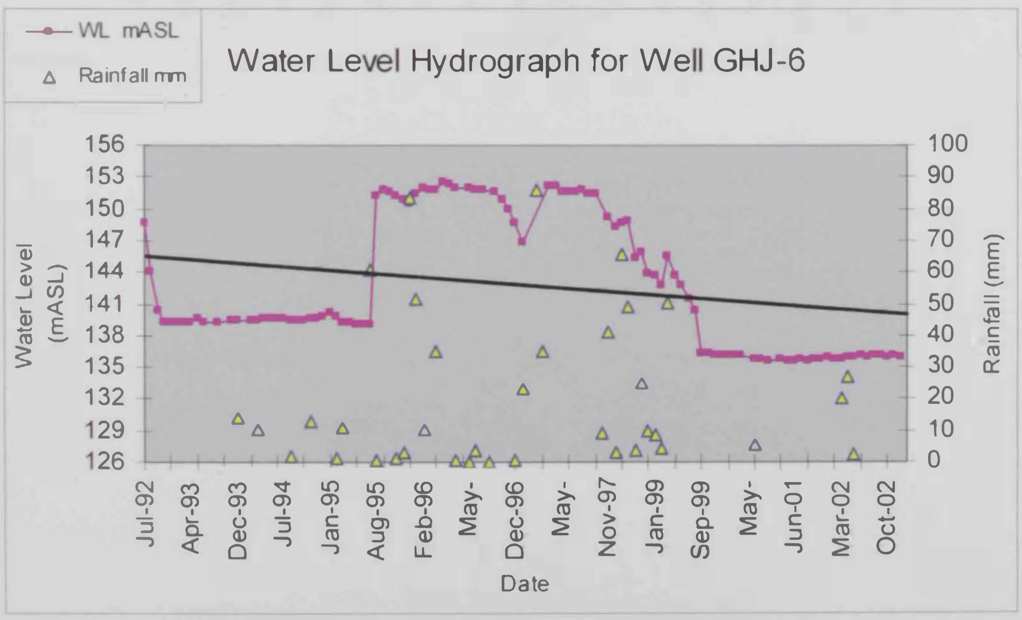

WL mASL
Rainfall mm
Water Level Hydrograph for Well DEO-10
Water Level (mASL)
2.0
1.0
0.0
-1.0
Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
Jan-89
Aug-89
May-90
Dec-90
Jul-91
Aug-92
Mar-93
Nov-93
Jun-94
Jan-95
Aug-95
May-96
Dec-96
Jul-97
Apr-98
Jan-99
May-02
Date

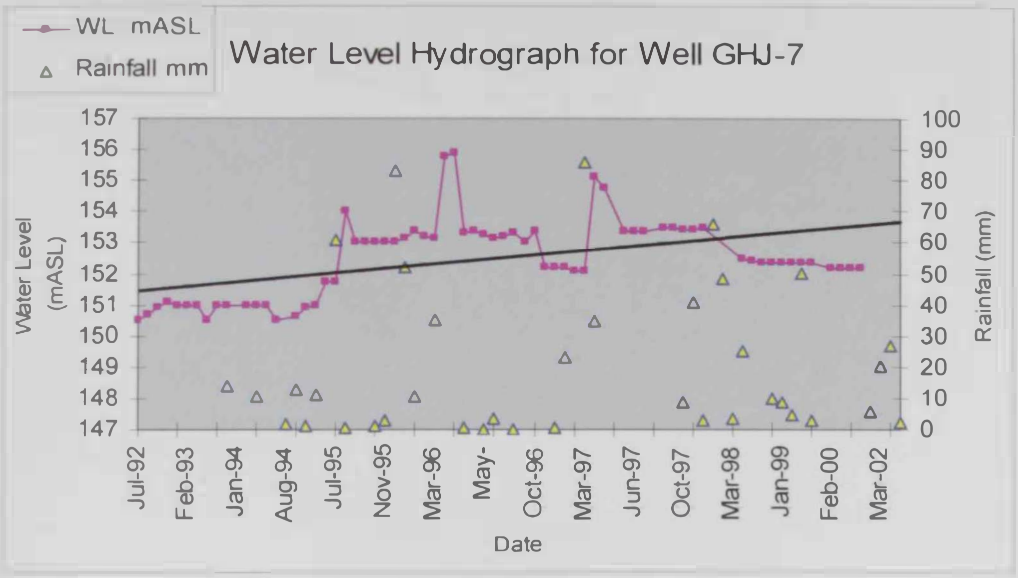

WL mASL
Rainfall mm
Water Level Hydrograph for Well SALLAN HAN
Water Level (mASL)
3
2
1
0
-1
-2
-3
-4
Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
May-82
Sep-83
Mar-85
Jun-86
Jul-87
Jun-88
Jul-89
Jan-91
Jul-92
Aug-93
Sep-94
Oct-95
Nov-96
Dec-97
Jan-99
Mar-00
Nov-01
Dec-02
Date

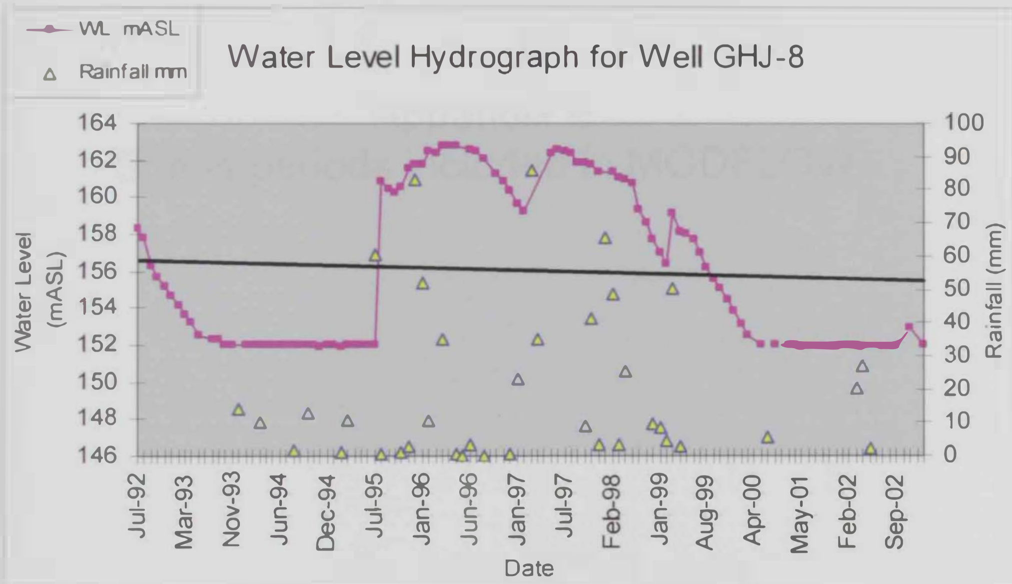

WL mASL
Rainfall mm
Water Level Hydrograph for Well GHJ-1
Water Level (mASL)
156
153
150
147
144
141
138
135
132
129
126
123
120
117
Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
Jul-92
Mar-93
Oct-93
Apr-94
Oct-94
Mar-95
Aug-95
Feb-96
Apr-96
Oct-96
Apr-97
Jul-97
Jan-98
Feb-99
Feb-01
Sep-01
May-
Dec-02
Date


WL mASL
Rainfall mm
Water Level Hydrograph for Well GHJ-1
Water Level (mASL)
Rainfall (mm)
Date


WL mASL
Rainfall mm
Water Level Hydrograph for Well GHJ-4
Water Level (mASL)
Rainfall (mm)
Date


WL mASL
Rainfall mm
Water Level Hydrograph for Well GHJ-6
Water Level (mASL)
Rainfall (mm)
Date


WL mASL
Rainfall mm
Water Level Hydrograph for Well GHJ-7
Water Level (mASL)
157
156
155
154
153
152
151
150
149
148
147
100
90
80
70
60
50
40
30
20
10
0
Rainfall (mm)
Jul-92
Feb-93
Jan-94
Aug-94
Jul-95
Nov-95
Mar-96
May-
Oct-96
Mar-97
Jun-97
Oct-97
Mar-98
Jan-99
Feb-00
Mar-02
Date


WL mASL
Rainfall mm
Water Level Hydrograph for Well GHJ-8
Water Level (mASL)
164
162
160
158
156
154
152
150
148
146
100
90
80
70
60
50
40
30
20
10
0
Rainfall (mm)
Jul-92
Mar-93
Nov-93
Jun-94
Dec-94
Jul-95
Jan-96
Jun-96
Jan-97
Jul-97
Feb-98
Jan-99
Aug-99
Apr-00
May-01
Feb-02
Sep-02
Date

Appendix E
Stress periods included in MODFLOW

Stress Periods	From	To	Mulaina Flow (m^3/d)	days	Mulaina Flow (m^3)	Sohar Flow (m^3)
1	1/1/1985	1/31/1985	0	31	0	0
2	2/1/1985	2/28/1985	0	28	0	0
3	3/1/1985	3/31/1985	0	31	0	0
4	4/1/1985	4/30/1985	0	30	0	0
5	5/1/1985	5/31/1985	0	31	0	0
6	6/1/1985	6/30/1985	0	30	0	0
7	7/1/1985	7/31/1985	0	31	0	0
8	8/1/1985	8/31/1985	0	31	0	0
9	9/1/1985	9/30/1985	0	30	0	0
10	10/1/1985	10/31/1985	0	31	0	0
11	11/1/1985	11/30/1985	0	30	0	0
12	12/1/1985	12/31/1985	0	31	0	0
13	1/1/1986	1/31/1986	0	31	0	0
14	2/1/1986	2/1/1986	58200	1	58200	0
15	2/2/1986	2/28/1986	0	27	0	0
16	3/1/1986	3/31/1986	0	31	0	0
17	4/1/1986	4/30/1986	0	30	0	0
18	5/1/1986	5/31/1986	0	31	0	0
19	6/1/1986	6/30/1986	0	30	0	0
20	7/1/1986	7/11/1986	0	11	0	0
21	7/12/1986	7/15/1986	25462.75	4	101851	0
22	7/16/1986	7/31/1986	0	16	0	0
23	8/1/1986	8/31/1986	0	31	0	0
24	9/1/1986	9/30/1986	0	30	0	0
25	10/1/1986	10/12/1986	0	12	0	0
26	10/13/1986	10/14/1986	14002	2	28004	0
27	10/15/1986	10/21/1986	0	7	0	0
28	10/22/1986	10/25/1986	8469.75	4	33879	0
29	10/26/1986	10/27/1986	0	2	0	0
30	10/28/1986	10/31/1986	10708.5	4	42834	0
31	11/1/1986	11/30/1986	0	30	0	0
32	12/1/1986	12/31/1986	0	31	0	0
33	1/1/1987	1/31/1987	0	31	0	26600
34	2/1/1987	2/20/1987	0	20	0	0
35	2/21/1987	2/22/1987	55289	2	110578	12420
36	2/23/1987	2/28/1987	0	6	0	0
37	3/1/1987	3/13/1987	0	13	0	0
38	3/14/1987	3/26/1987	81656.08	13	1061529	56340
39	3/27/1987	3/31/1987	357216.6	5	1786083	1416960
40	4/1/1987	4/6/1987	28286.33	6	169718	0
41	4/7/1987	4/14/1987	375361.4	8	3002891	126000
42	4/15/1987	4/30/1987	2062.5	16	33000	0
43	5/1/1987	5/30/1987	1766.667	30	53000	0
44	5/31/1987	5/31/1987	0	1	0	0
45	6/1/1987	6/1/1987	0	1	0	0
46	6/2/1987	6/21/1987	8336.4	20	166728	0
47	6/22/1987	6/26/1987	0	5	0	0
48	6/27/1987	6/27/1987	2340	1	2340	0
49	6/28/1987	6/30/1987	0	3	0	0
50	7/1/1987	7/30/1987	0	30	0	0
51	7/31/1987	7/31/1987	269585	1	269585	0
52	8/1/1987	8/7/1987	80458.14	7	563207	0

Stress Periods	From	To	Mulaina Flow (m^3/d)	days	Mulaina Flow (m^3)	Sohar Flow (m^3)
53	8/8/1987	8/20/1987	72143.77	13	937869	0
54	8/21/1987	8/31/1987	459436.5	11	5053802	128700
55	9/1/1987	9/28/1987	123430.5	28	3456053	0
56	9/29/1987	9/30/1987	0	2	0	0
57	10/1/1987	10/31/1987	0	31	0	0
58	11/1/1987	11/5/1987	0	5	0	0
59	11/6/1987	11/7/1987	1600	2	3200	0
60	11/8/1987	11/8/1987	0	1	0	0
61	11/9/1987	11/9/1987	2354	1	2354	0
62	11/10/1987	11/30/1987	0	21	0	0
63	12/1/1987	12/31/1987	0	31	0	0
64	1/1/1988	1/3/1988	0	3	0	0
65	1/4/1988	1/4/1988	136970	1	136970	0
66	1/5/1988	1/31/1988	0	27	0	0
67	2/1/1988	2/16/1988	0	16	0	491000
68	2/17/1988	2/24/1988	3613519	8	28908150	44103300
69	2/25/1988	2/29/1988	549946	5	2749730	0
70	3/1/1988	3/31/1988	194610	31	6032910	0
71	4/1/1988	4/25/1988	46572.4	25	1164310	0
72	4/26/1988	4/30/1988	124920	5	624600	0
73	5/1/1988	5/31/1988	29626.77	31	918430	0
74	6/1/1988	6/28/1988	7405	28	207340	0
75	6/29/1988	6/30/1988	0	2	0	0
76	7/1/1988	7/6/1988	0	6	0	0
77	7/7/1988	7/12/1988	2666.667	6	16000	0
78	7/13/1988	7/24/1988	0	12	0	0
79	7/25/1988	7/28/1988	16700	4	66800	0
80	7/29/1988	7/31/1988	223333.3	3	670000	615000
81	8/1/1988	8/14/1988	19214.29	14	269000	0
82	8/15/1988	8/31/1988	43187.06	17	734180	1370000
83	9/1/1988	9/20/1988	161826.5	20	3236530	0
84	9/21/1988	9/30/1988	210738	10	2107380	0
85	10/1/1988	10/6/1988	5328.333	6	31970	0
86	10/7/1988	10/31/1988	0	25	0	0
87	11/1/1988	11/30/1988	0	30	0	0
88	12/1/1988	12/31/1988	0	31	0	0
89	1/1/1989	1/31/1989	0	31	0	0
90	2/1/1989	2/28/1989	0	28	0	0
91	3/1/1989	3/17/1989	0	17	0	0
92	3/18/1989	3/31/1989	44640.29	14	624964	0
93	4/1/1989	4/10/1989	566.7	10	5667	0
94	4/11/1989	4/30/1989	0	20	0	0
95	5/1/1989	5/31/1989	0	31	0	0
96	6/1/1989	6/30/1989	0	30	0	0
97	7/1/1989	7/31/1989	0	31	0	0
98	8/1/1989	8/31/1989	0	31	0	0
99	9/1/1989	9/30/1989	0	30	0	0
100	10/1/1989	10/31/1989	0	31	0	0
101	11/1/1989	11/6/1989	0	6	0	0
102	11/7/1989	11/8/1989	211365	2	422730	0
103	11/9/1989	11/30/1989	0	22	0	0
104	12/1/1989	12/6/1989	0	6	0	0

Stress Periods	From	To	Mulaina Flow (m^3/d)	days	Mulaina Flow (m^3)	Sohar Flow (m^3)
105	12/7/1989	12/8/1989	68854	2	137708	0
106	12/9/1989	12/15/1989	0	7	0	0
107	12/16/1989	12/31/1989	161367.5	16	2581880	2403840
108	1/1/1990	1/6/1990	7725.333	6	46352	0
109	1/7/1990	1/31/1990	0	25	0	0
110	2/1/1990	2/6/1990	0	6	0	0
111	2/7/1990	2/28/1990	692828.2	22	15242220	4722927
112	3/1/1990	3/31/1990	75251.61	31	2332800	383400
113	4/1/1990	4/30/1990	30327.47	30	909824	0
114	5/1/1990	5/31/1990	5725.516	31	177491	0
115	6/1/1990	6/30/1990	10721.73	30	321652	0
116	7/1/1990	7/22/1990	2814.136	22	61911	0
117	7/23/1990	7/31/1990	17280	9	155520	0
118	8/1/1990	8/31/1990	16161.13	31	500995	0
119	9/1/1990	9/30/1990	24080	30	722400	0
120	10/1/1990	10/16/1990	14202.88	16	227246	0
121	10/17/1990	10/31/1990	0	15	0	0
122	11/1/1990	11/30/1990	0	30	0	0
123	12/1/1990	12/31/1990	0	31	0	0
124	1/1/1991	1/31/1991	0	31	0	0
125	2/1/1991	2/28/1991	0	28	0	0
126	3/1/1991	3/6/1991	0	6	0	0
127	3/7/1991	3/15/1991	151242.1	9	1361179	0
128	3/16/1991	3/26/1991	0	11	0	0
129	3/27/1991	3/31/1991	1238440	5	6192200	2116707
130	4/1/1991	4/24/1991	16452.25	24	394854	774291
131	4/25/1991	4/30/1991	0	6	0	0
132	5/1/1991	5/31/1991	0	31	0	0
133	6/1/1991	6/30/1991	0	30	0	0
134	7/1/1991	7/31/1991	0	31	0	0
135	8/1/1991	8/31/1991	0	31	0	0
136	9/1/1991	9/30/1991	0	30	0	0
137	10/1/1991	10/31/1991	0	31	0	0
138	11/1/1991	11/30/1991	0	30	0	0
139	12/1/1991	12/31/1991	0	31	0	864630
140	1/1/1992	1/18/1992	0	18	0	0
141	1/19/1992	1/22/1992	46584	4	186336	0
142	1/23/1992	1/25/1992	0	3	0	0
143	1/26/1992	1/26/1992	651600	1	651600	0
144	1/27/1992	2/4/1992	0	9	0	0
145	1/28/1992	1/31/1992	0	4	0	0
146	2/1/1992	2/4/1992	0	4	0	0
147	2/5/1992	2/29/1992	64907.6	25	1622690	110257
148	3/1/1992	3/19/1992	7927.368	19	150620	0
149	3/20/1992	3/31/1992	0	12	0	0
150	4/1/1992	4/1/1992	0	1	0	0
151	4/2/1992	4/30/1992	65185.86	29	1890390	980948
152	5/1/1992	5/15/1992	4376	15	65640	0
153	5/16/1992	5/31/1992	0	16	0	0
154	6/1/1992	6/30/1992	0	30	0	0
155	7/1/1992	7/19/1992	0	19	0	0
156	7/20/1992	7/26/1992	34952.14	7	244665	0

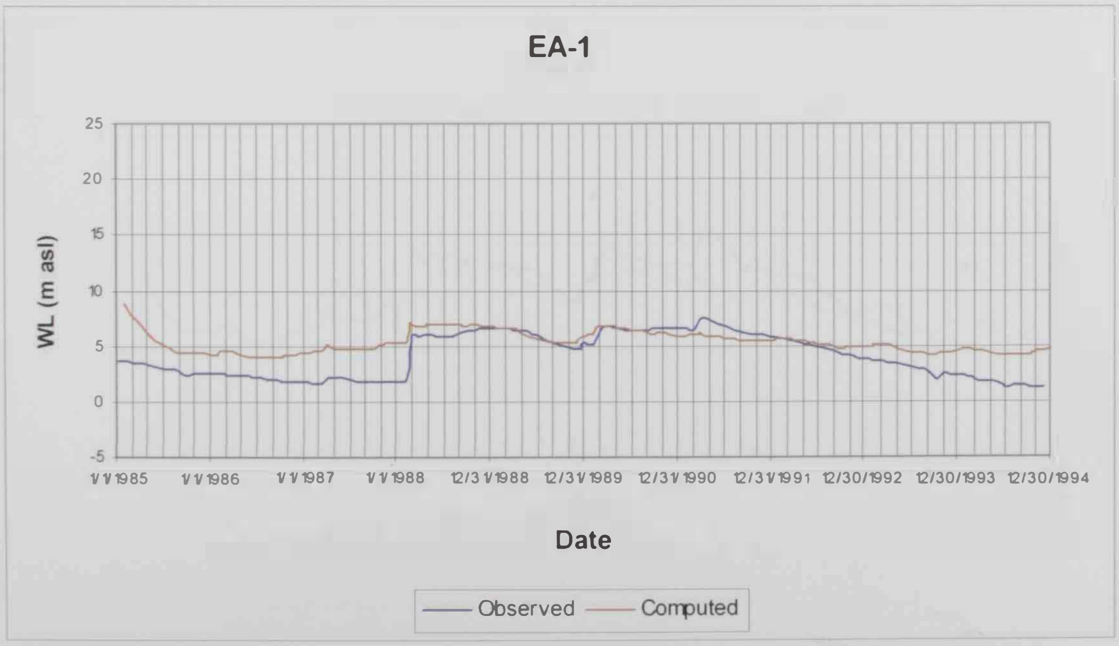
Stress Periods	From	To	Mulaina Flow (m^3/d)	days	Mulaina Flow (m^3)	Sohar Flow (m^3)
105	12/7/1989	12/8/1989	68854	2	137708	0
106	12/9/1989	12/15/1989	0	7	0	0
107	12/16/1989	12/31/1989	161367.5	16	2581880	2403840
108	1/1/1990	1/6/1990	7725.333	6	46352	0
109	1/7/1990	1/31/1990	0	25	0	0
110	2/1/1990	2/6/1990	0	6	0	0
111	2/7/1990	2/28/1990	692828.2	22	15242220	4722927
112	3/1/1990	3/31/1990	75251.61	31	2332800	383400
113	4/1/1990	4/30/1990	30327.47	30	909824	0
114	5/1/1990	5/31/1990	5725.516	31	177491	0
115	6/1/1990	6/30/1990	10721.73	30	321652	0
116	7/1/1990	7/22/1990	2814.136	22	61911	0
117	7/23/1990	7/31/1990	17280	9	155520	0
118	8/1/1990	8/31/1990	16161.13	31	500995	0
119	9/1/1990	9/30/1990	24080	30	722400	0
120	10/1/1990	10/16/1990	14202.88	16	227246	0
121	10/17/1990	10/31/1990	0	15	0	0
122	11/1/1990	11/30/1990	0	30	0	0
123	12/1/1990	12/31/1990	0	31	0	0
124	1/1/1991	1/31/1991	0	31	0	0
125	2/1/1991	2/28/1991	0	28	0	0
126	3/1/1991	3/6/1991	0	6	0	0
127	3/7/1991	3/15/1991	151242.1	9	1361179	0
128	3/16/1991	3/26/1991	0	11	0	0
129	3/27/1991	3/31/1991	1238440	5	6192200	2116707
130	4/1/1991	4/24/1991	16452.25	24	394854	774291
131	4/25/1991	4/30/1991	0	6	0	0
132	5/1/1991	5/31/1991	0	31	0	0
133	6/1/1991	6/30/1991	0	30	0	0
134	7/1/1991	7/31/1991	0	31	0	0
135	8/1/1991	8/31/1991	0	31	0	0
136	9/1/1991	9/30/1991	0	30	0	0
137	10/1/1991	10/31/1991	0	31	0	0
138	11/1/1991	11/30/1991	0	30	0	0
139	12/1/1991	12/31/1991	0	31	0	864630
140	1/1/1992	1/18/1992	0	18	0	0
141	1/19/1992	1/22/1992	46584	4	186336	0
142	1/23/1992	1/25/1992	0	3	0	0
143	1/26/1992	1/26/1992	651600	1	651600	0
144	1/27/1992	2/4/1992	0	9	0	0
145	1/28/1992	1/31/1992	0	4	0	0
146	2/1/1992	2/4/1992	0	4	0	0
147	2/5/1992	2/29/1992	64907.6	25	1622690	110257
148	3/1/1992	3/19/1992	7927.368	19	150620	0
149	3/20/1992	3/31/1992	0	12	0	0
150	4/1/1992	4/1/1992	0	1	0	0
151	4/2/1992	4/30/1992	65185.86	29	1890390	980948
152	5/1/1992	5/15/1992	4376	15	65640	0
153	5/16/1992	5/31/1992	0	16	0	0
154	6/1/1992	6/30/1992	0	30	0	0
155	7/1/1992	7/19/1992	0	19	0	0
156	7/20/1992	7/26/1992	34952.14	7	244665	0

Stress Periods	From	To	Mulaina Flow (m^3/d)	days	Mulaina Flow (m^3)	Sohar Flow (m^3)
157	7/27/1992	7/31/1992	0	5	0	0
158	8/1/1992	8/31/1992	0	31	0	0
159	9/1/1992	9/30/1992	0	30	0	0
160	10/1/1992	10/4/1992	0	4	0	0
161	10/5/1992	10/5/1992	82074	1	82074	0
162	10/6/1992	10/31/1992	0	26	0	0
163	11/1/1992	11/30/1992	0	30	0	0
164	12/1/1992	12/31/1992	0	31	0	0
165	1/1/1993	1/31/1993	0	31	0	0
166	2/1/1993	2/6/1993	0	6	0	0
167	2/7/1993	2/28/1993	34567.91	22	760494	0
168	3/1/1993	3/12/1993	2865.583	12	34387	0
169	3/13/1993	3/31/1993	0	19	0	0
170	4/1/1993	4/30/1993	0	30	0	0
171	5/1/1993	5/31/1993	0	31	0	0
172	6/1/1993	6/30/1993	0	30	0	0
173	7/1/1993	7/31/1993	0	31	0	0
174	8/1/1993	8/31/1993	0	31	0	0
175	9/1/1993	9/30/1993	0	30	0	0
176	10/1/1993	10/31/1993	0	31	0	0
177	11/1/1993	11/30/1993	0	30	0	0
178	12/1/1993	12/31/1993	0	31	0	0
179	1/1/1994	1/31/1994	0	31	0	505440
180	2/1/1994	2/28/1994	0	28	0	0
181	3/1/1994	3/31/1994	0	31	0	131501
182	4/1/1994	4/30/1994	0	30	0	0
183	5/1/1994	5/31/1994	0	31	0	0
184	6/1/1994	6/30/1994	0	30	0	0
185	7/1/1994	7/6/1994	0	6	0	0
186	7/7/1994	7/12/1994	157147.2	6	942883	0
187	7/13/1994	7/31/1994	0	19	0	0
188	8/1/1994	8/31/1994	0	31	0	0
189	9/1/1994	9/7/1994	0	7	0	0
190	9/8/1994	9/10/1994	575712	3	1727136	0
191	9/11/1994	9/30/1994	0	20	0	0
192	10/1/1994	10/7/1994	0	7	0	0
193	10/8/1994	10/11/1994	141436.8	4	565747	0
194	10/12/1994	10/15/1994	0	4	0	0
195	10/16/1994	10/31/1994	22901.5	16	366424	0
196	11/1/1994	11/6/1994	777.6667	6	4666	0
197	11/7/1994	11/30/1994	0	24	0	0
198	12/1/1994	12/31/1994	0	31	0	0

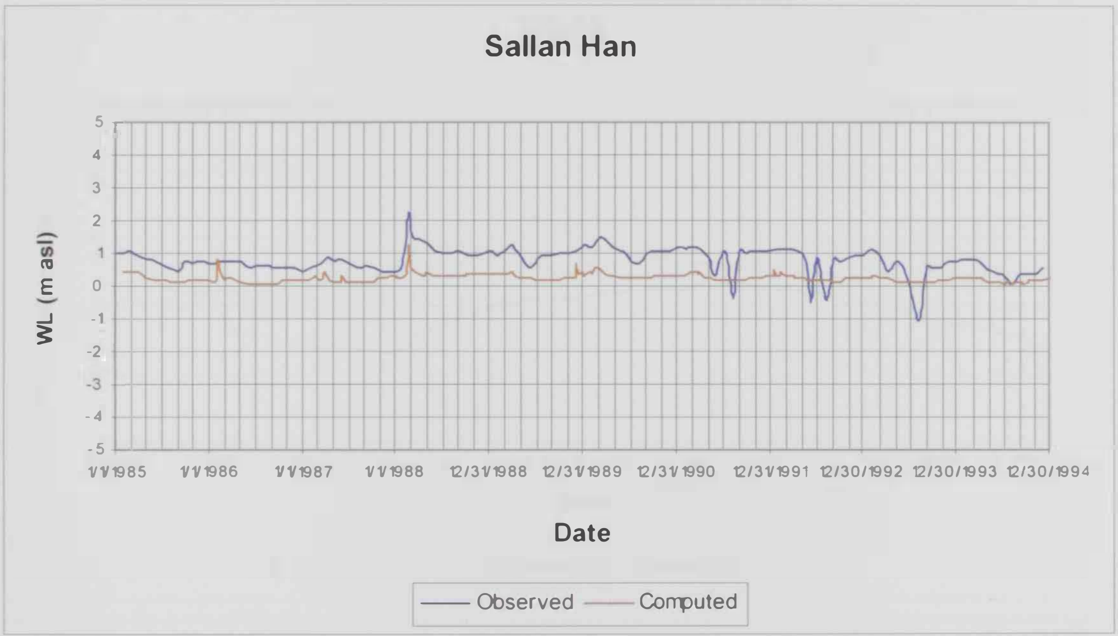
Appendix F
Results of model calibration

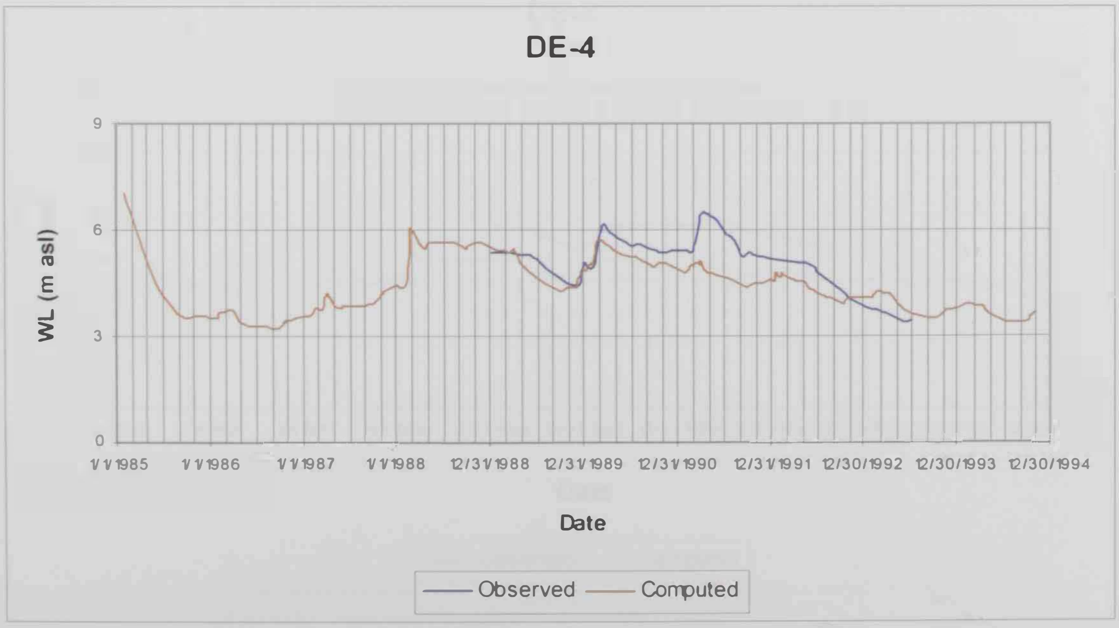

OA-1
WL (m asl)
120
100
80
60
40
20
0
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed

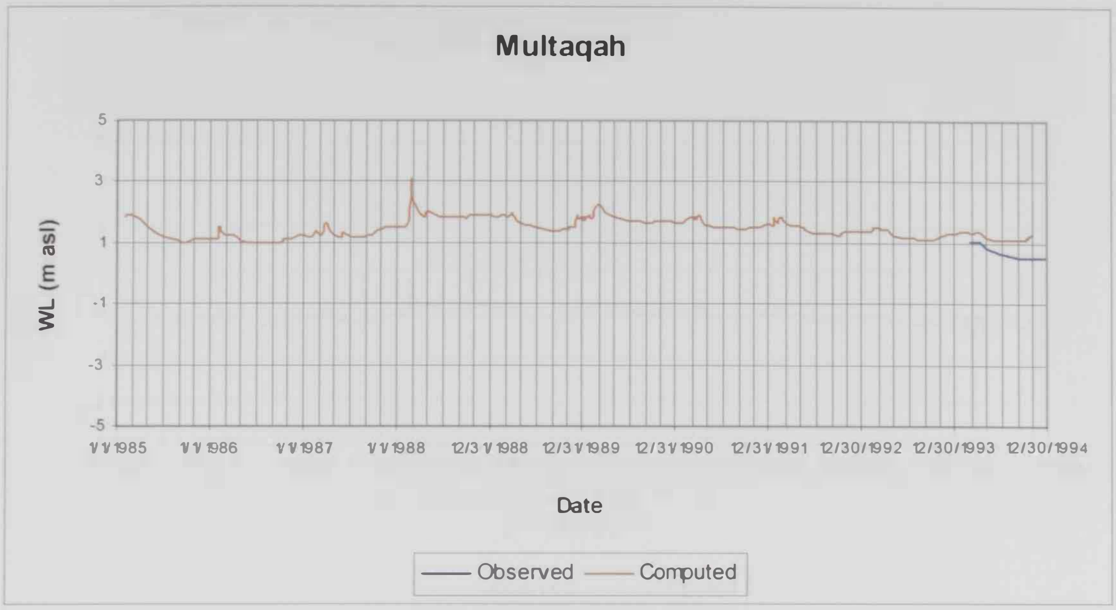

JA-4
WL(m asl)
35
30
25
20
15
10
5
0
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed


EA-1
WL (m asl)
25
20
15
10
5
0
-5
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed


JA-2
WL (m asl)
Date
Observed
Corrputed


Sallan Han
WL (m asl)
Date
Observed
Computed

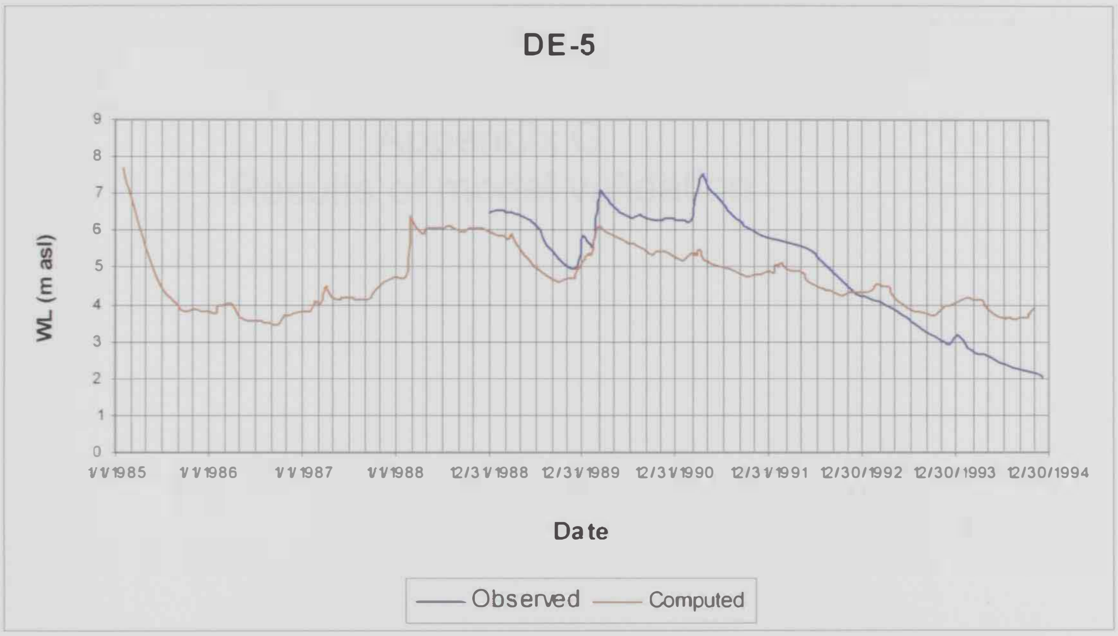

DE-4
WL (m asl)
Date
Observed
Computed

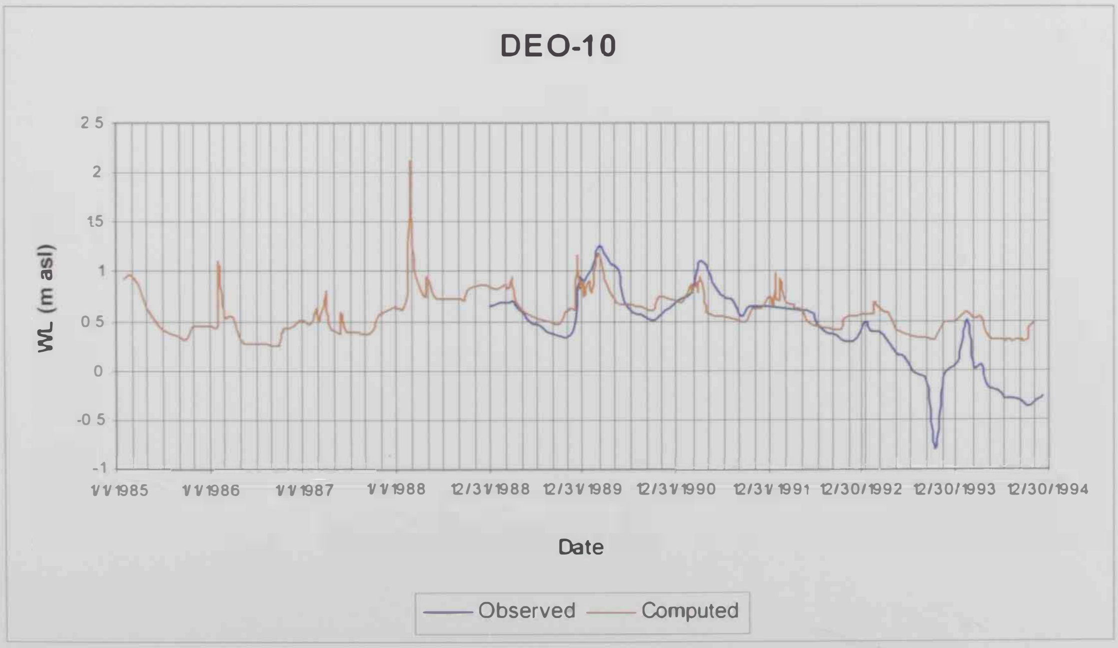

Multaqah
WL (m asl)
5
3
1
-1
-3
-5
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed


HS-12
WL (m asl)
20
15
10
5
0
-5
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed

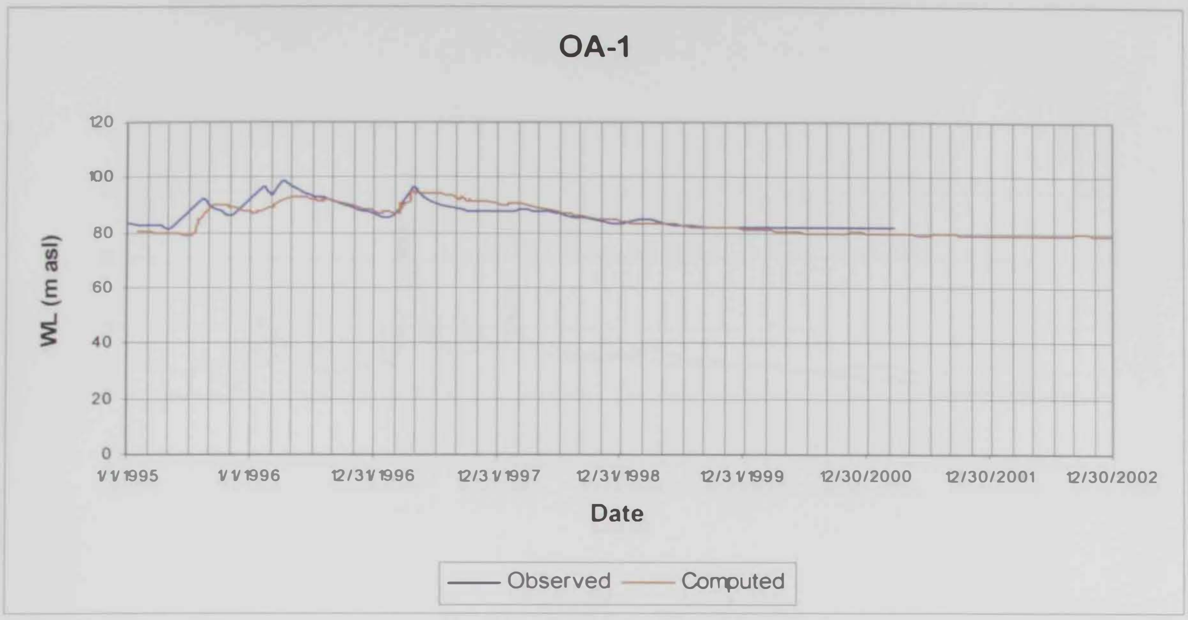

DE-2
WL (m asl)
20
15
10
5
0
-5
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed


BD88268
WL (m asl)
9
7
5
3
1
-1
-3
-5
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed

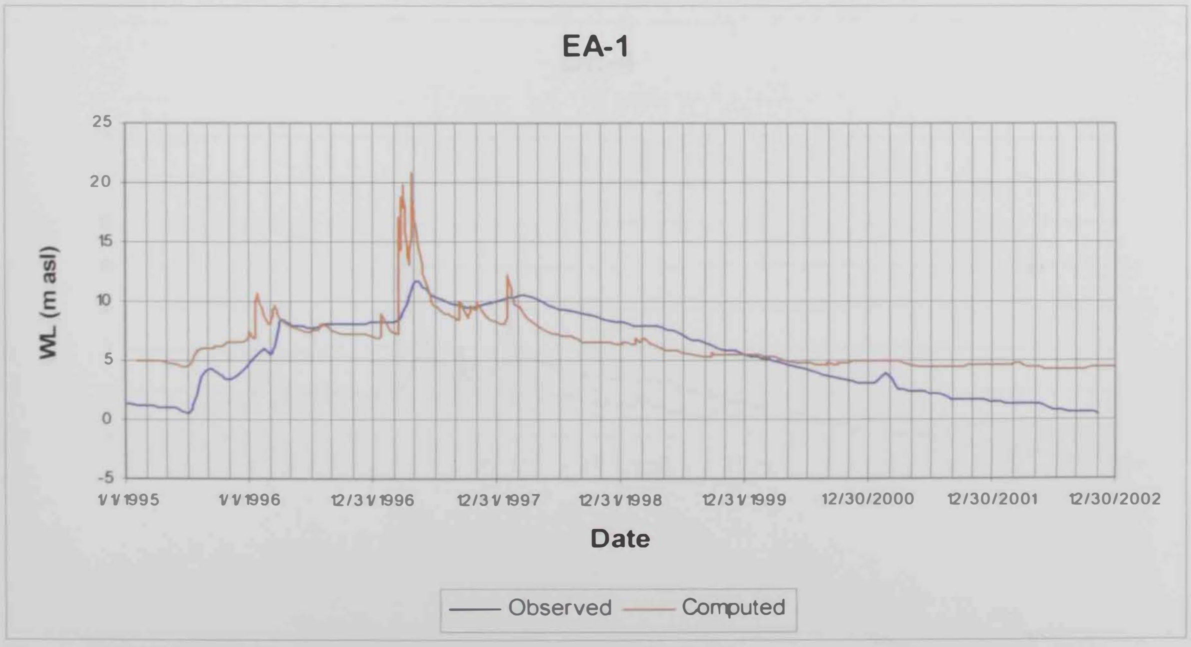

DE-5
WL (m asl)
9
8
7
6
5
4
3
2
1
0
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed


DEO-10
WL (m asl)
2.5
2
1.5
1
0.5
0
-0.5
-1
1/1/1985
1/1/1986
1/1/1987
1/1/1988
12/31/1988
12/31/1989
12/31/1990
12/31/1991
12/30/1992
12/30/1993
12/30/1994
Date
Observed
Computed

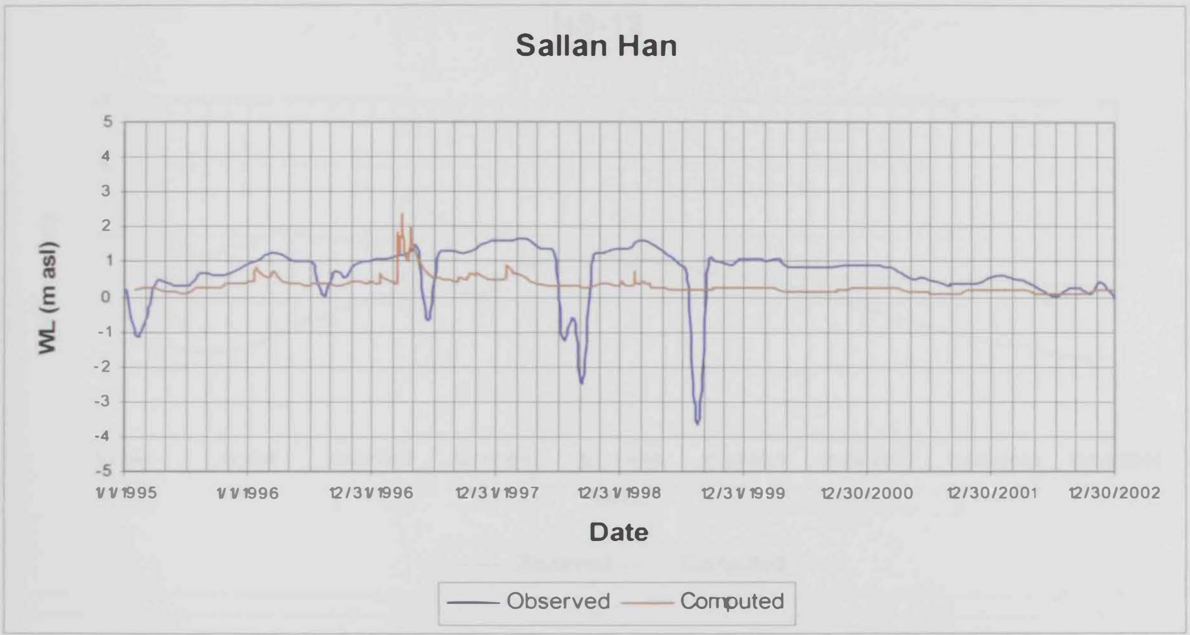
Appendix G
Results of model validation


OA-1
WL (m asl)
120
100
80
60
40
20
0
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

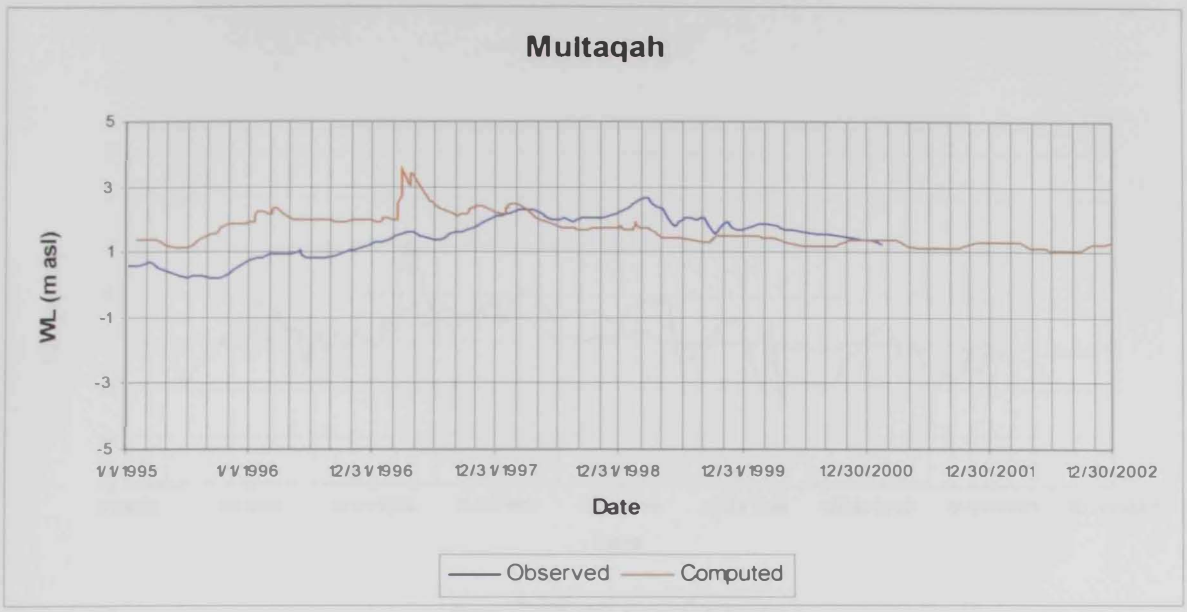

JA-4
WL (m asl)
40
35
30
25
20
15
10
5
0
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed


EA-1
WL (m asl)
25
20
15
10
5
0
-5
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

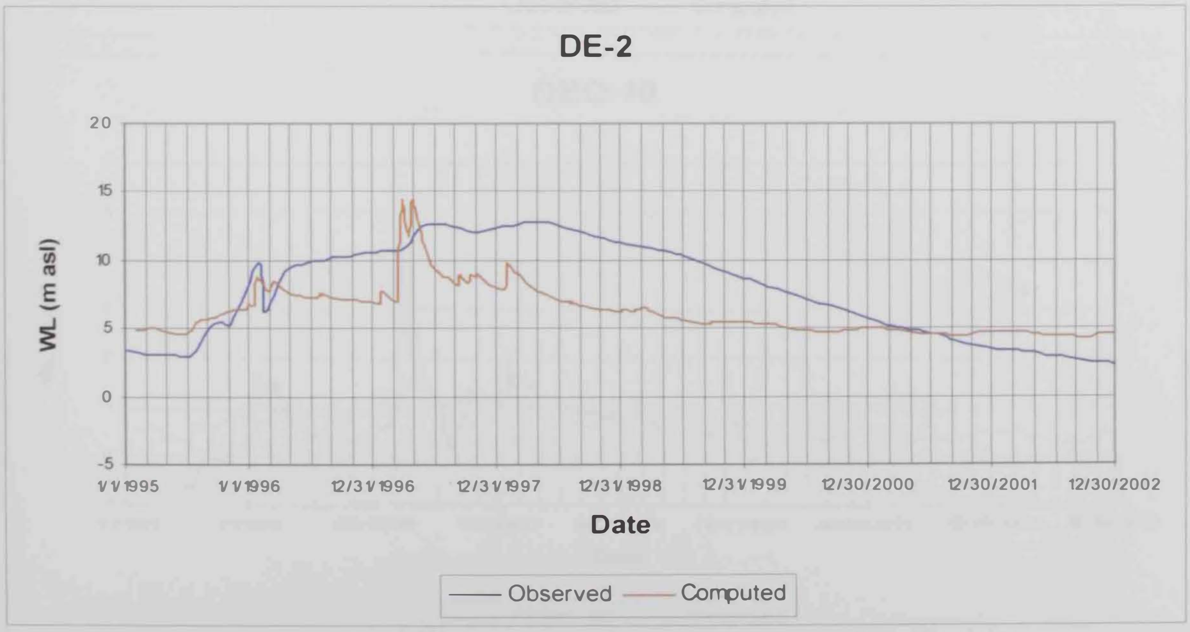

JA-2
WL (m asl)
20
15
10
5
0
-5
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

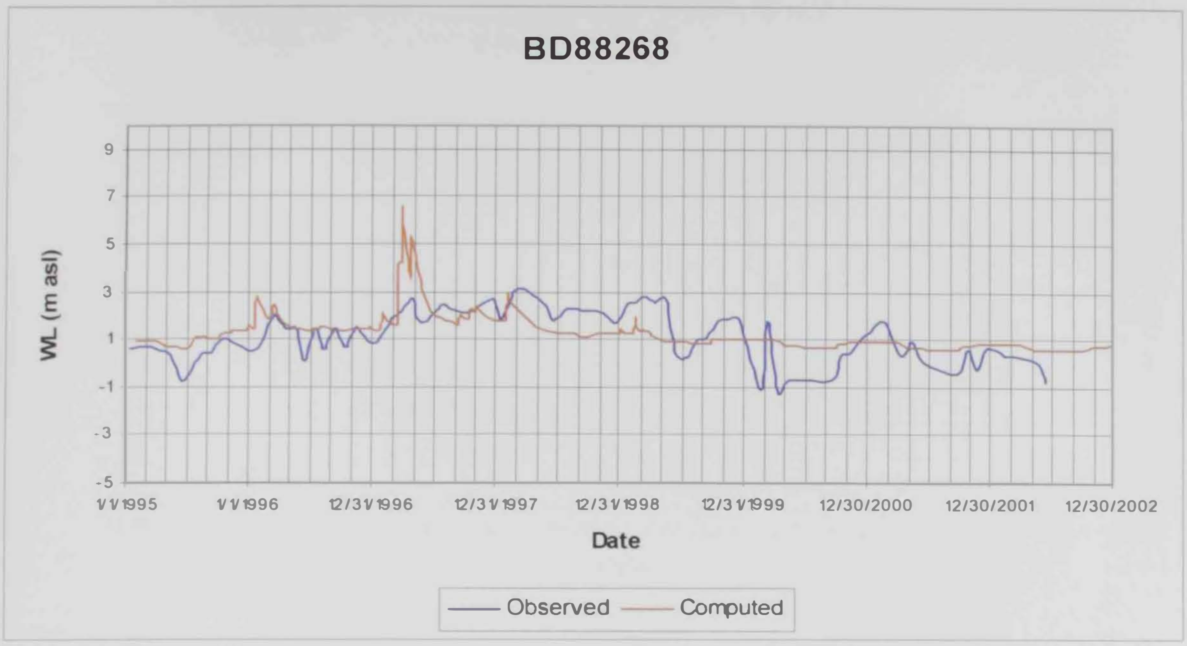

Sallan Han
WL (m asl)
5
4
3
2
1
0
-1
-2
-3
-4
-5
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed


DE-4
WL (m asl)
24
21
18
15
12
9
6
3
0
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

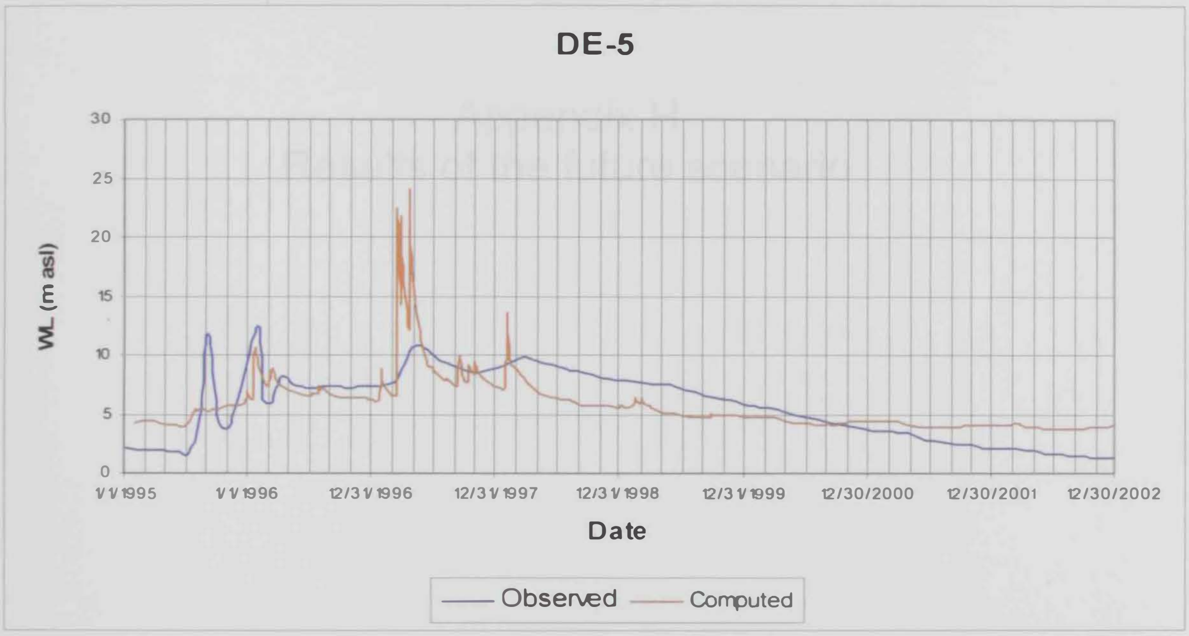

Multaqah
WL (m asl)
5
3
1
-1
-3
-5
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed


HS-12
WL (m asl)
20
15
10
5
0
-5
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

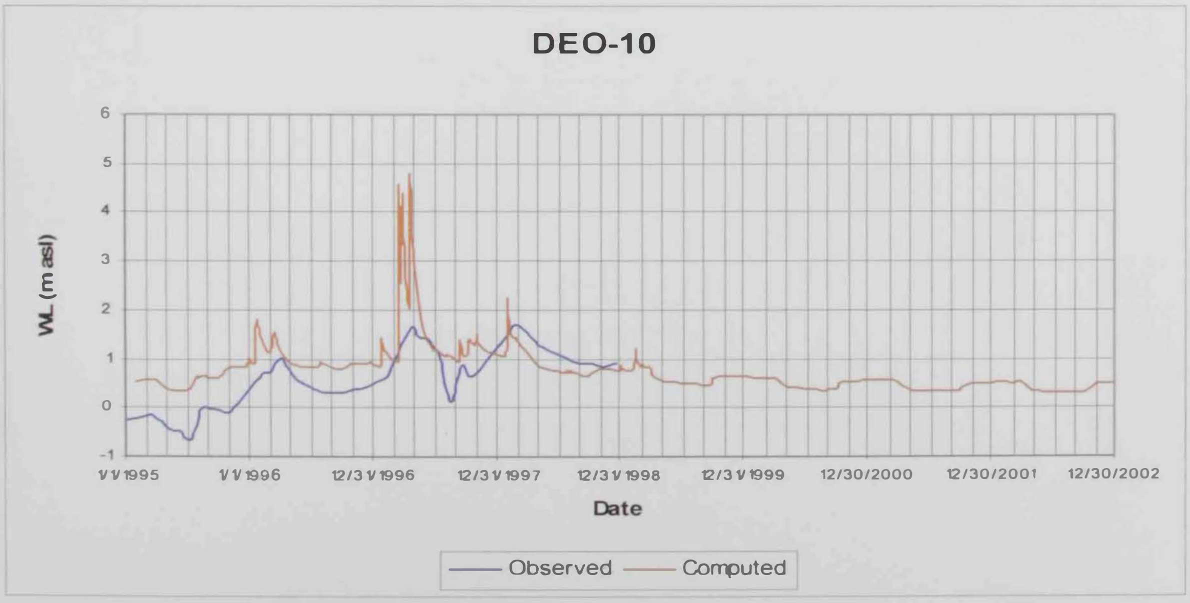

DE-2
WL (m asl)
20
15
10
5
0
-5
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed



BD88268
WL (m asl)
9
7
5
3
1
-1
-3
-5
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

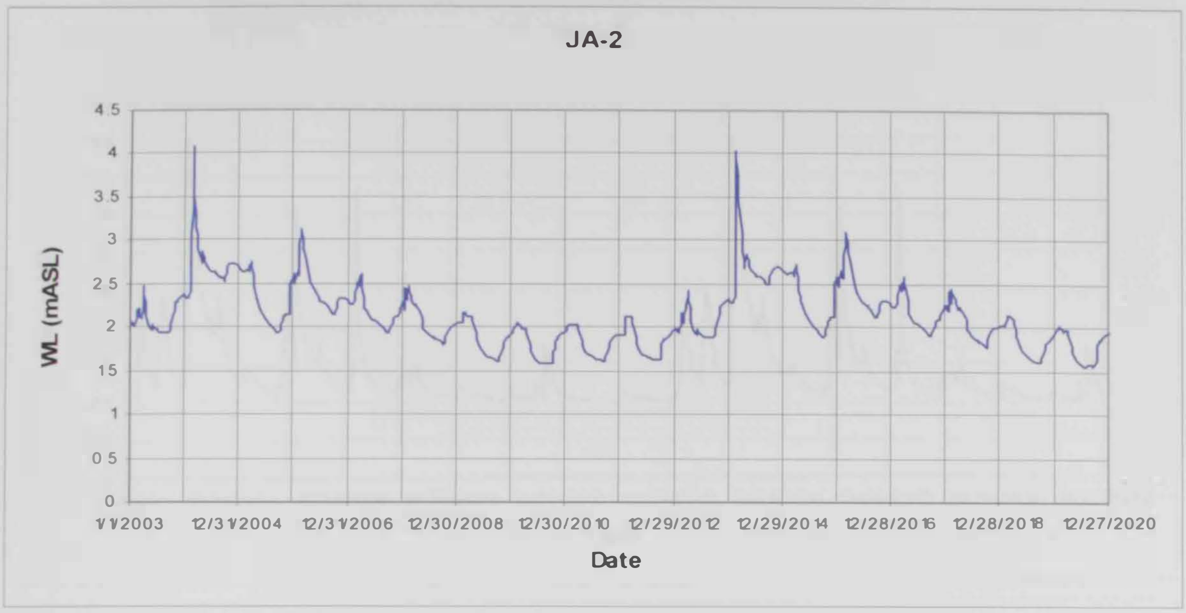


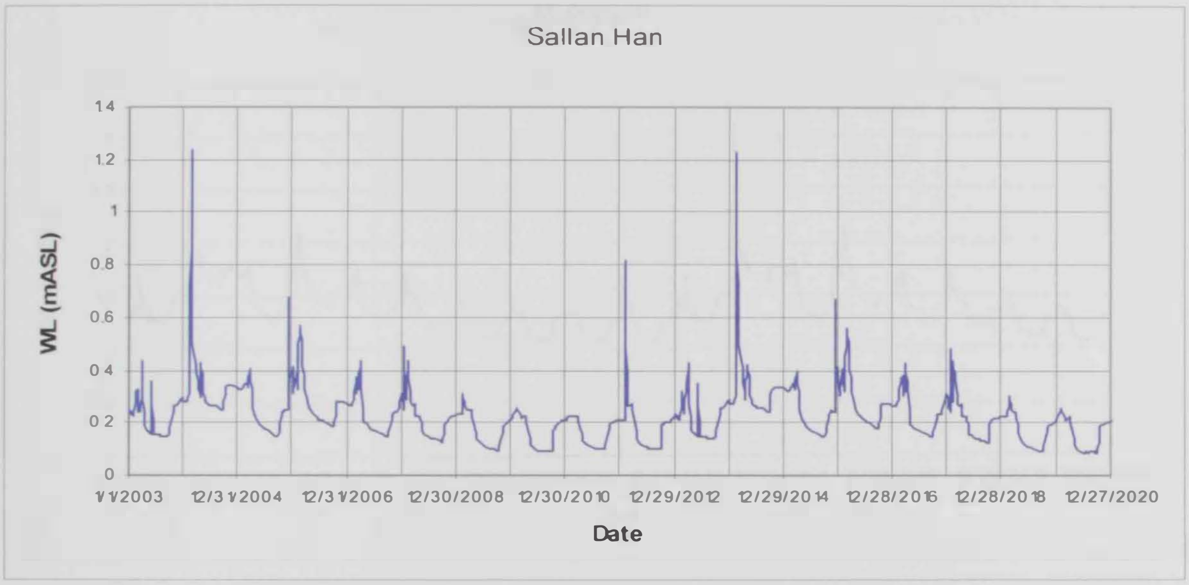
DE-5
WL (m asl)
30
25
20
15
10
5
0
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

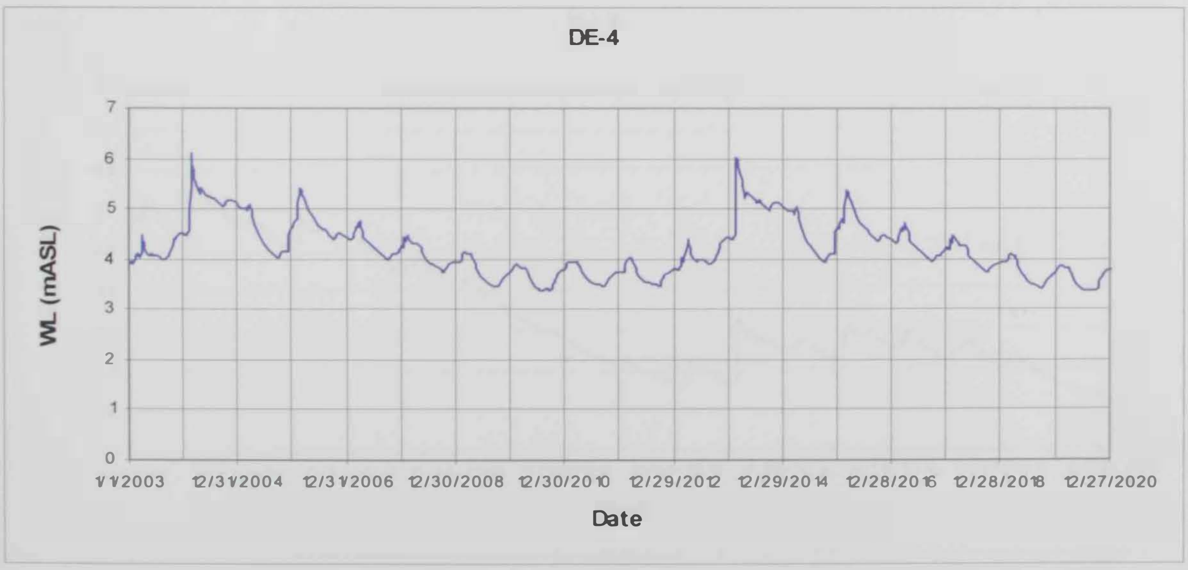


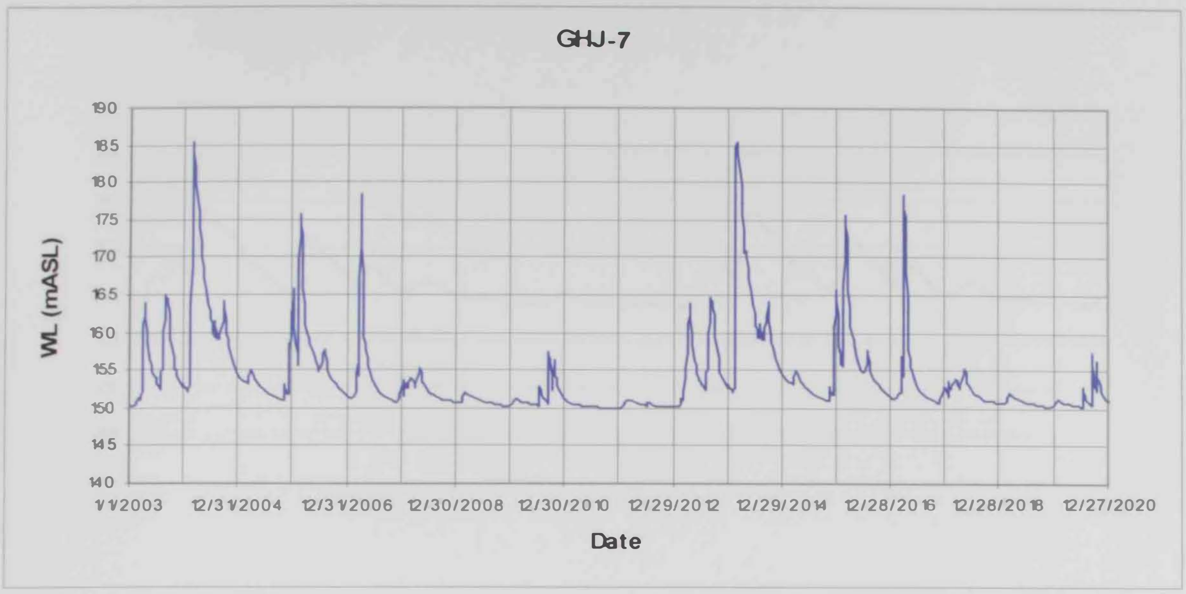
DEO-10
WL (m asl)
6
5
4
3
2
1
0
-1
1/1/1995
1/1/1996
12/31/1996
12/31/1997
12/31/1998
12/31/1999
12/30/2000
12/30/2001
12/30/2002
Date
Observed
Computed

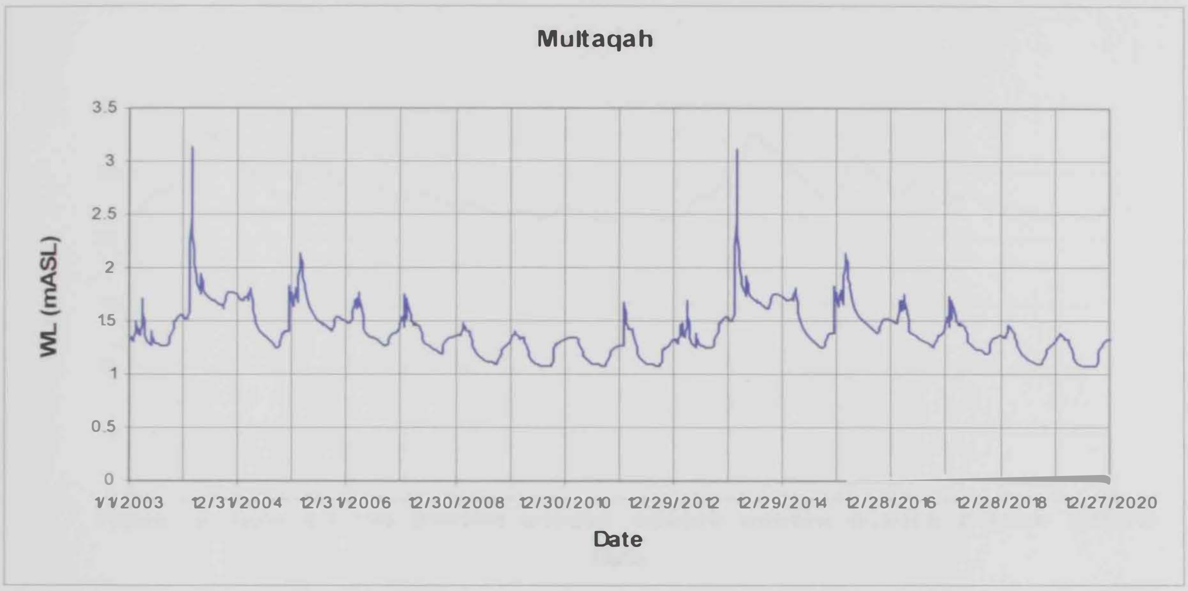
Appendix H
Results of the future scenario

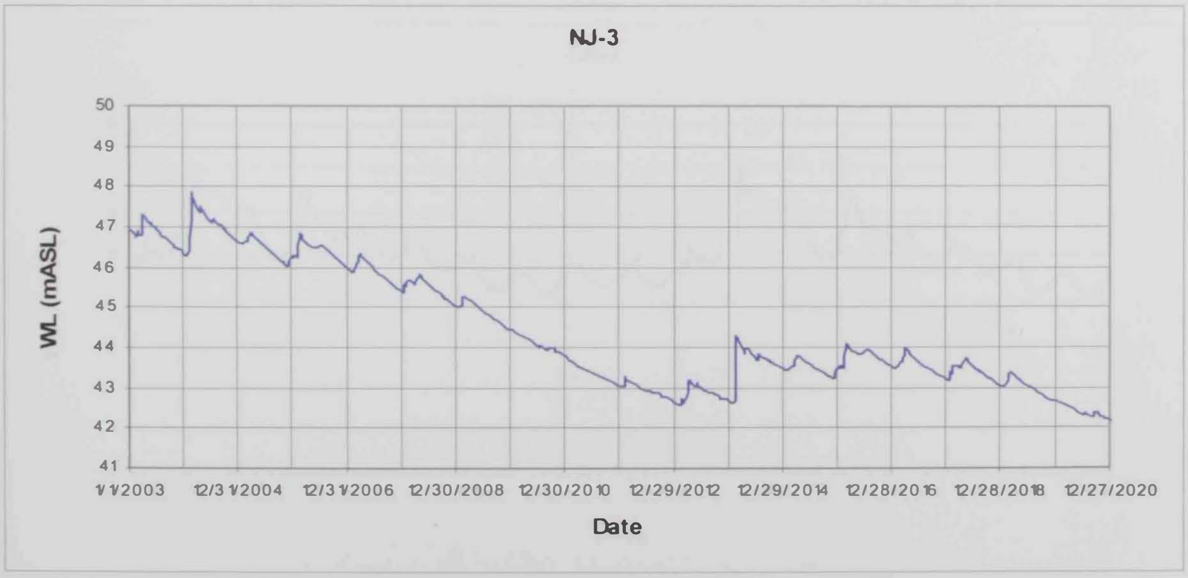

JA-2
WL (mASL)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


Sallan Han
WL (mASL)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date

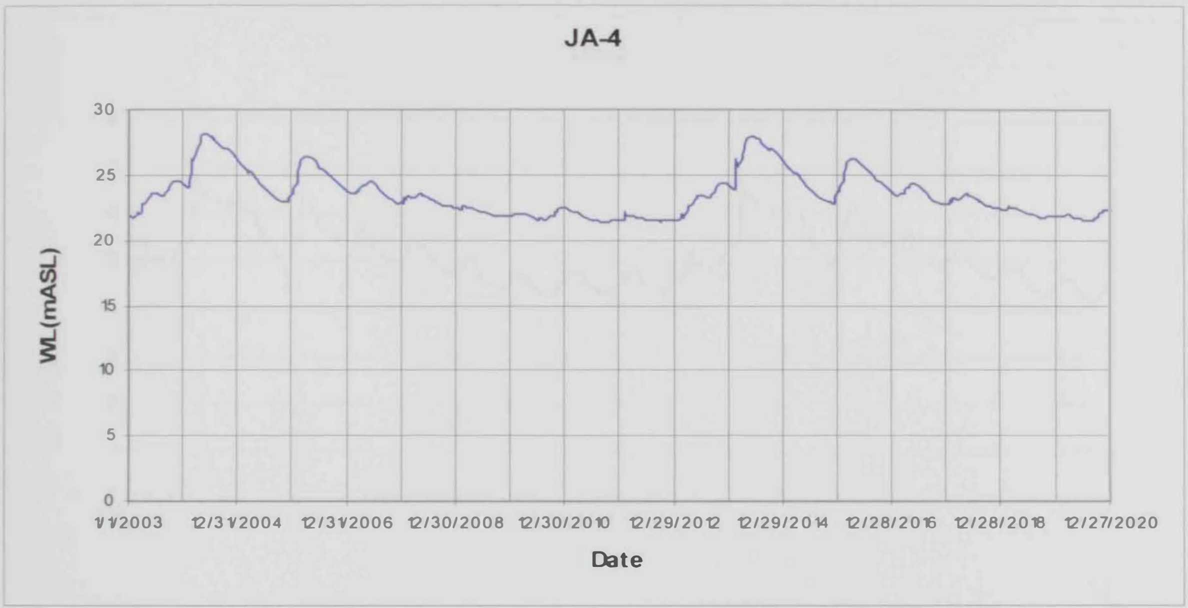

DE-4
WL (mASL)
7
6
5
4
3
2
1
0
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date

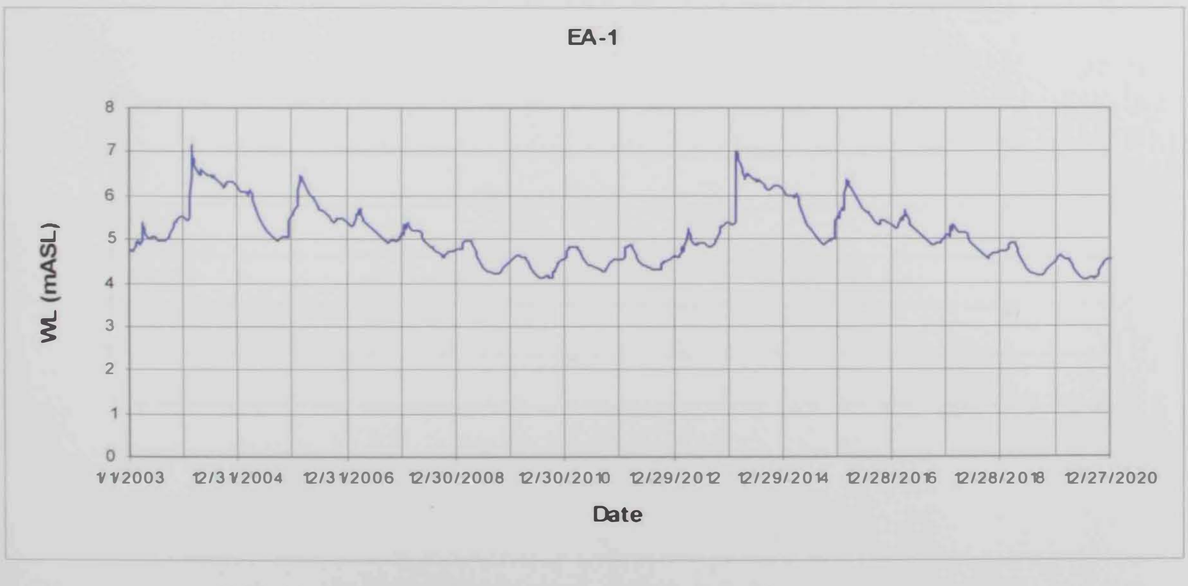

GHJ-7
190
185
180
175
170
165
160
155
150
145
140
WL (mASL)
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


Multaqah
3.5
3
2.5
2
1.5
1
0.5
0
WL (mASL)
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date

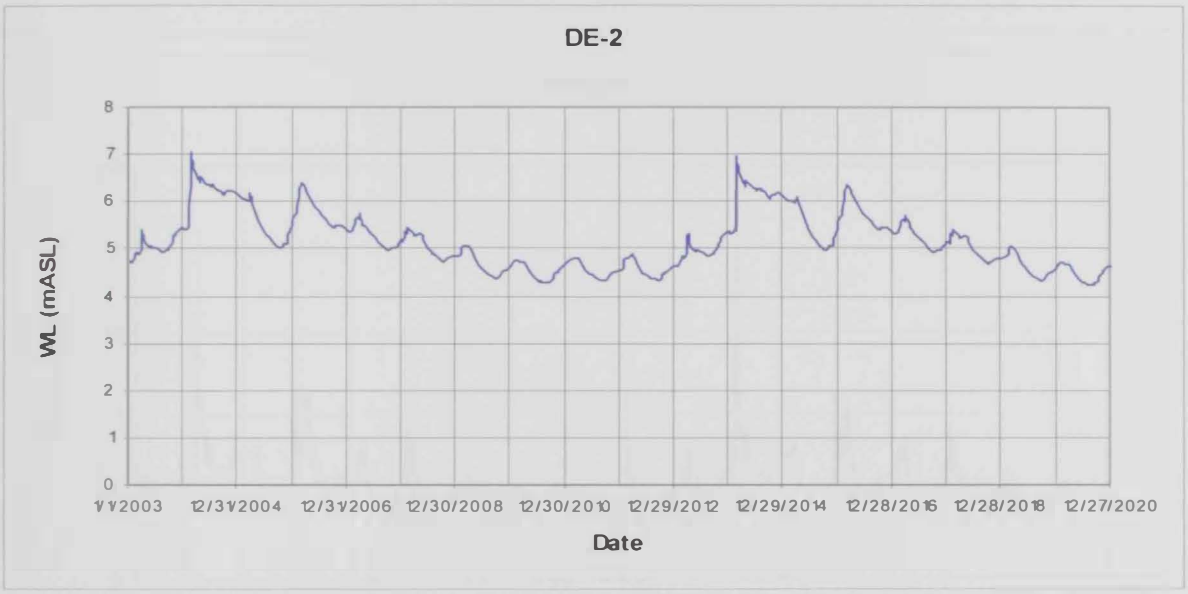

NJ-3
50
49
48
47
46
45
44
43
42
41
WL (mASL)
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


OA-1
100
95
90
85
80
75
70
65
60
WL(m ASL)
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date

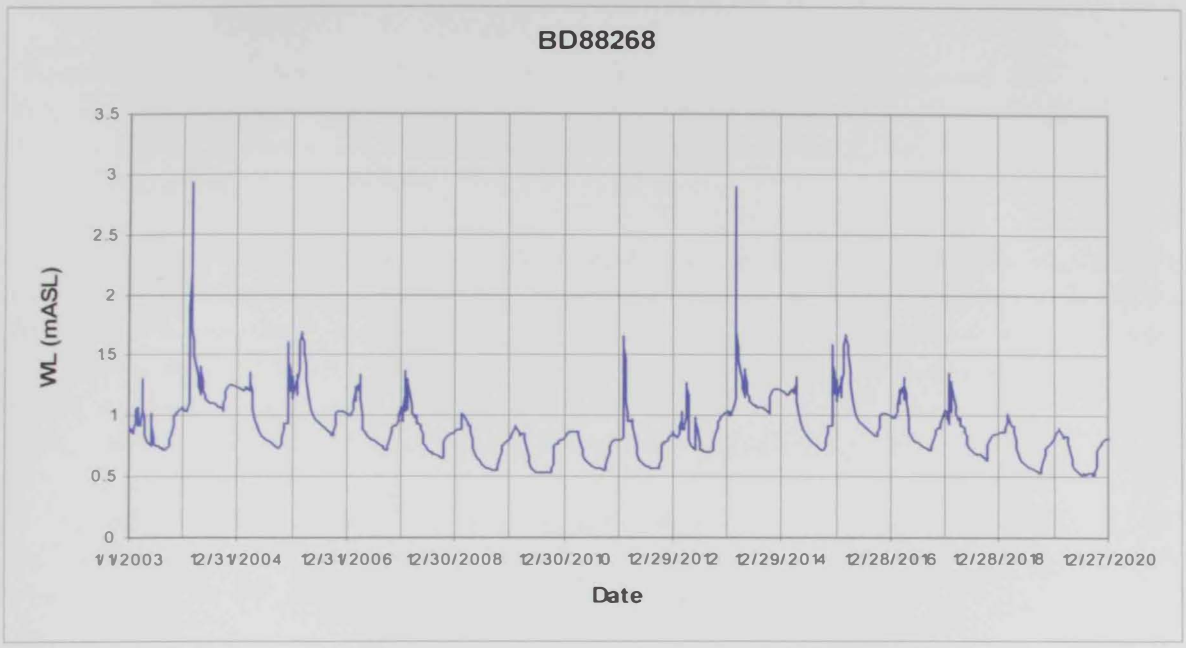

JA-4
30
25
20
15
10
5
0
WL(mASL)
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date

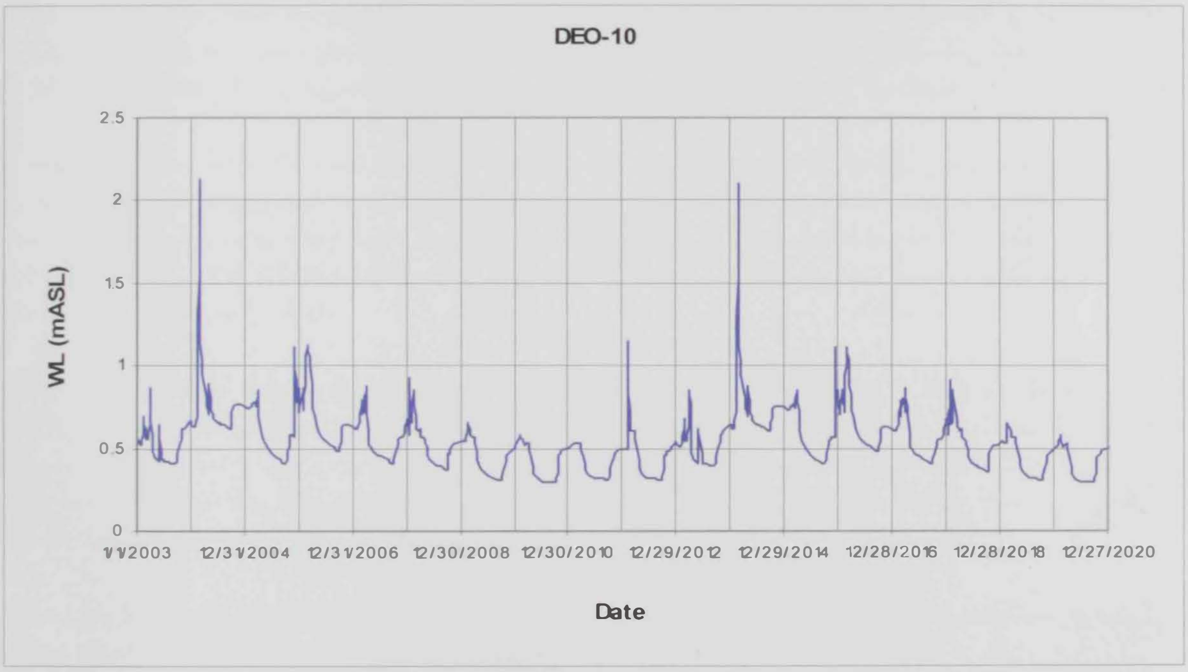

EA-1
8
7
6
5
4
3
2
1
0
WL (mASL)
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


HS-12
WL (mASL)
0
1
2
3
4
5
6
7
8
9
10
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


DE-2
WL (mASL)
0
1
2
3
4
5
6
7
8
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


DE-5
WL (mASL)
0
1
2
3
4
5
6
7
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


BD88268
WL (mASL)
3.5
3
2.5
2
1.5
1
0.5
0
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date


DEO-10
WL (mASL)
2.5
2
1.5
1
0.5
0
1/1/2003
12/31/2004
12/31/2006
12/30/2008
12/30/2010
12/29/2012
12/29/2014
12/28/2016
12/28/2018
12/27/2020
Date

ملخص الرسالة

يعتبر الماء مصدرا هاما واستراتيجيا لدول العالم وخصوصا في البلدان الجافة وشبه الجافة التي تتضمن سلطنة عمان. في مثل هذه البلدان التي تتصف بمناخها الحار وقلة الأمطار فيها تعتبر المياه الجوفية المصدر الرئيسي للمياه العذبة. وبالتالي يصبح تقييم هذه المياه أمرا ضروريا لوضع إستراتيجية طويلة المدى تكفل استمرارية هذا الشريان الحيوي للسنوات القادمة بما يتفق مع متطلبات العصر والتطور الذي يشهده العالم.

ولقد أدت الزيادة في عدد السكان إلى هبوط ملحوظ في مستويات المياه الجوفية نتيجة لزيادة الطلب عليها بسبب ازدياد النشاطات الزراعية والصناعية الذي واكب التطور الذي شهدته سلطنة عمان منذ عام 1970 وحتى الآن. إن الزيادة المطرده على المياه الجوفية مع قلة الأمطار السنوية أدت إلى الإخلال بالميزان المائي كما وكيفا حيث تقدر كميات المياه المستغلة للأغراض الزراعية بنسبة 92 %. وتولي حكومة سلطنة عمان ممثلة في وزارة البلديات الإقليمية والبيئة وموارد المياه جل اهتمامها على حماية مصادر المياه الجوفية وتنميتها واستغلالها الاستغلال الأمثل من خلال وجود شبكة مراقبة هيدرولوجية منتشرة على كافة الأحواض المائية من اجل مراقبة مستويات المياه وكميات الأمطار وجريان الأودية.

وكنتيجة لهدر كميات كبيره من مياه السيول للبحر أو الصحاري فقد اتخذت الوزارة تدابير من اجل الاستفادة بأكبر كمية من مياه السيول وذلك بإنشاء سدود التغذية الجوفية على الأودية الرئيسية منذ منتصف الثمانينات وحتى الآن إذ بلغ عدد هذه السدود ثمانية عشرا سدا ولا تزال هناك خطط من اجل سدود أخرى لزيادة التغذية الجوفية من مياه الأمطار.

إن الإدارة الفعالة لمصادر المياه الجوفيةِ وإدارتها بالشكل الذي يضمن استمراريتها هو أمر بالغ الأهمية في البلدان الجافة وشبه الجافة. ومن اجل تحقيق هذا الهدف وبجانب انشاء السدود في سلطنة عمان أوجدت التشريعات التي تحدد استخدامات المياه وطرق إدارتها ويتم تشجيع المزارعين على استخدام أنظمة الري الحديثة للتقليل من استنزاف المياه.

وتأتي أهمية هذه الدراسة لتقييم كفاءة سدود التغذية الجوفية في حجز المياه السطحية من السيول وتغذية مخزون الماء الجوفي بها من خلال استخدام نماذج رياضية لمحاكاة جريان المياه الجوفية في وادي الجزي بسلطنة عمان وعمل تقييم لكميات المياه المتجمعة في موقع السد ومقدار تغذية المياه الجوفية الناتجة عن ذلك. وقد تمت معايرة نموذج المياه الجوفية على البيانات المتوفرة في الفترة من 1985-2002 وتنبؤ للمستقبل حتى عام 2020. وقد تم توفير البيانات الخاصة بهذه الدراسة من وزارة البلديات الإقليمية والبيئة وموارد المياه.

ومن خلال استخدام الخرائط الطبوغرافية فقد تم تحديد حدود الوادي وتحديد روافد وادي الجزي الرئيسية وتم عمل تحليل شامل للتغيرات في كميات الأمطار والجريان ومناسيب المياه الجوفية اعتمادا على البيانات المسجلة في محطات الرصد وفي آبار المراقبة وتم دراسة الأوضاع الجيولوجية والهيدرولوجية لمنطقة الدراسة. كما تضمنت الدراسة استخدام نموذج رياضي ثلاثي الأبعاد لدراسة حركة المياه الجوفية وعمل تقييم كمي لتغذية المياه الجوفية من السد وقد ساعد النموذج أيضا في دراسة اتجاهات حركة المياه الجوفية والموازنة المائية للمياه الجوفية في الخزان.

وقد خلصت الدراسة إلى عدة استنتاجات حيث تبين أن الأمطار ذات طبيعة غير منتظمة ويقدر المتوسط السنوي بحوالي 120 مم وتنعكس طبيعة هذه الأمطار على مقدار الجريان الذي هو بدوره غير منتظم.

من خلال نتائج الموازنة المائية للنموذج الرياضي للمياه الجوفية تبين أن السد يقوم بدور فعال في تغذية المياه الجوفية حيث قدرت الزدياده فيما يترشح منه إلى الخزان الجوفي بنسبة 36 % عن فترة ما قبل انشاء السد وهذا يظهر بشكل واضح وملموس في ارتفاع مناسيب المياه الجوفية في آبار المراقبة خصوصا تلك التي تقع مباشرة في أسفل السد. وبالرغم من فقدان كميات من المياه السطحية إلا انه يتضح من خلال دراسة اتجاهات حركة المياه الجوفية والموازنة المائية أن التغذية من السد تساهم بشكل واضح في تقليل تداخل مياه البحر في الخزان الجوفي.

وبناء على نتائج هذه الدراسة فقد تم طرح بعض التوصيات للدراسات المستقبلية والإدارة المثلى للمياه الجوفية منها: ان ضخ المياه الجوفية من وادي الجزي يجب ان يقلل ويرشد قدر الامكان مع بناء قاعدة بيانات متكاملة تحتوي على البيانات والمعلومات الجيولوجية والهيدرولوجية الدقيقه التي تسمح بتقييم افضل لموارد المياه الجوفية في المنطقة. كما ان تطوير النموذج الرياضي الحالي سيساهم في اعطاء رؤية مستقبلية للوضع المائي بعد عام 2020 م، اضافة الى وضع عدة حلول تساعد في الحفاظ على موارد المياه في الحوض الجوفي لوادي الجزي مع الاخذ في الحسبان الاعتبارات السياسية والاقتصادية والاجتماعية للمنطقة. ومن المهم جدا القيام بتحديث وتطوير الخطة الوطنية لموارد المياه بما يتناسب والاوضاع المائية الراهنة والمستقبلية.

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عمادة الدراسات العليا

عنوان الرسالة:

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اســـم الباحث: راشد بن سعيد بن عبدالله الكندي

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لإستكمال متطلبات الحصول على درجة الماجستير

في

العلوم فى موارد المياه

إعداد

راشد بن سعيد الكندي

جامعة الامارات العربية المتحدة
يونيو 2004